SEWAGE AND INDUSTRIAL WASTES

(Formerly Sewage Works Journal)

JOURNAL of the FEDERATION OF SEWAGE AND INDUSTRIAL WASTES ASSOCIATIONS

Special Features

1956 Literature Review, Part III—Research Committee Water Pollution

B.O.D. of Sewage Fractions—Balmat

Sewage Aeration Requirements—Bargman et al.

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JULY, 1957—VOL. 29, No. 7

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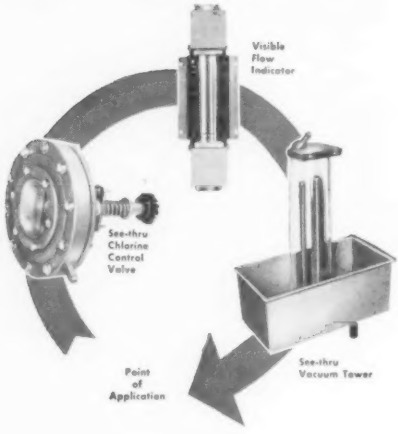

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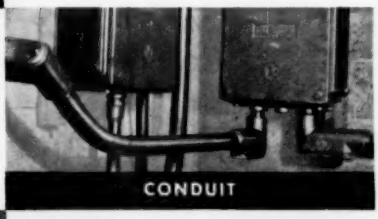

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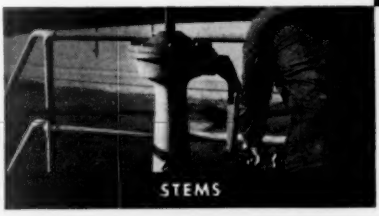

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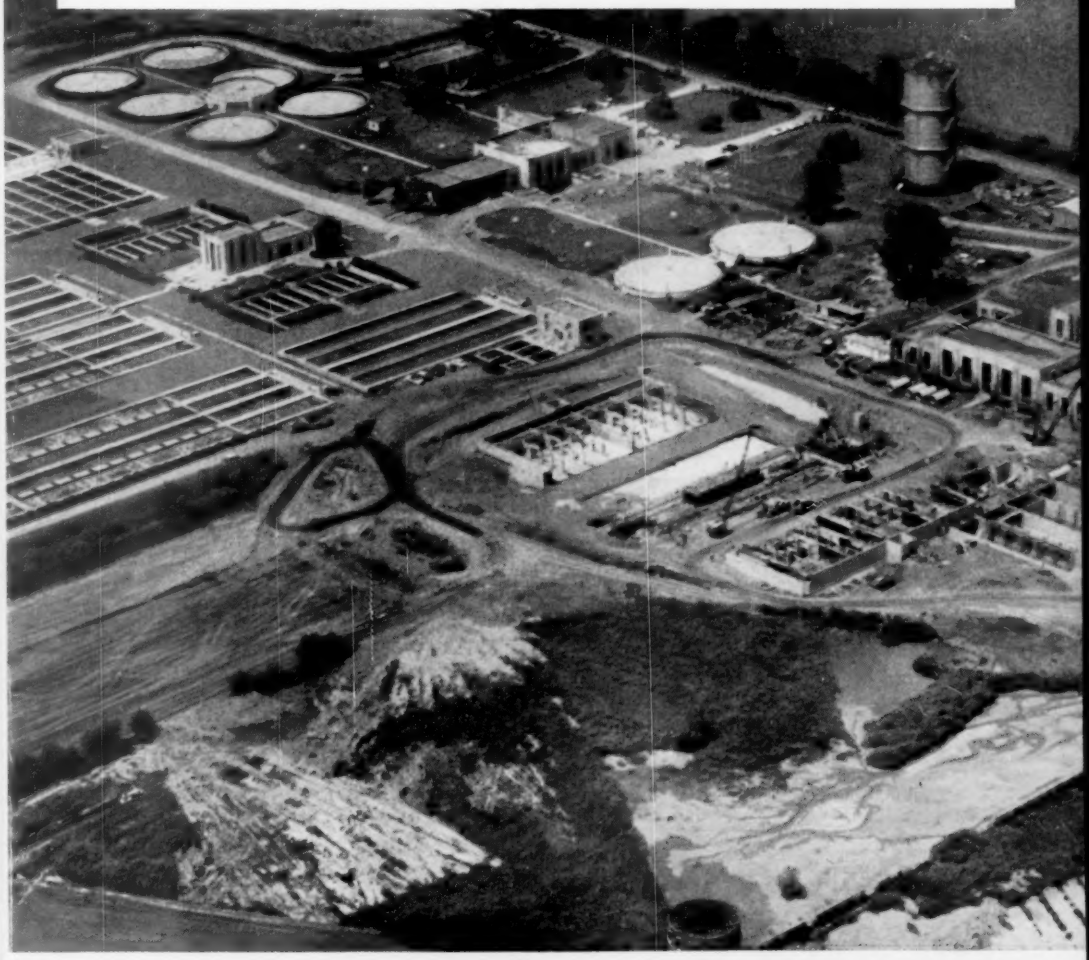

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October 7–10, 1957

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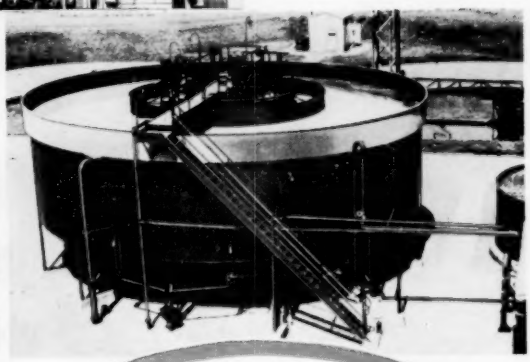

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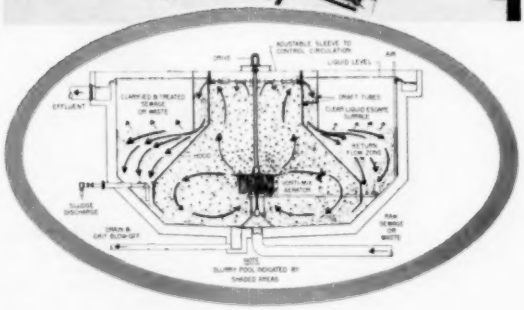

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Figure 1—Aeration gallery, showing Bailey Meters which measure the aerated sewage, air, and return sludge.

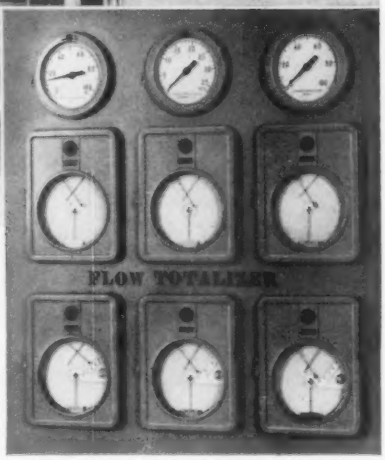

Figure 2—Bailey Electronic Flow Totalizers sum up total sewage, air, and sludge flows measured at individual gallery stations, showing at a glance the plant's performance.

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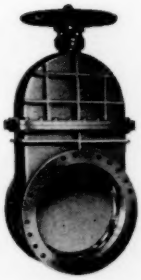

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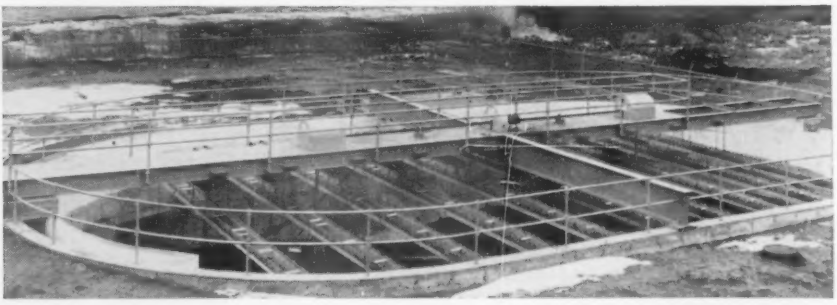
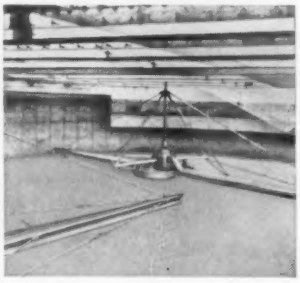


Construction view of unique settling tank at Wilson & Co. waste treatment plant, Albert Lea, Minn. This new high-rate anaerobic digestion process for treating packing plant waste was developed jointly by W. J. Fullen of Austin, Minn., and Professor G. J. Schroepfer, University of Minnesota. Plant was designed by A. J. Steffen, Wilson & Co. Sanitary Engineer, and the Consulting Engineering firm of Toltz, King, Duvall, Anderson and Associates, Inc.



Close-up of Unitube headers.

THE PROBLEM: Wilson & Co. at Albert Lea, Minnesota, needed an efficient treatment plant for handling packing plant waste. Pilot plant work and investigation by consulting engineers and Mr. Steffen indicated the need for a sludge removal device to meet these rigid requirements:

1. Complete removal of sludge from tank bottom for each revolution of sludge removal device (8½ min.)
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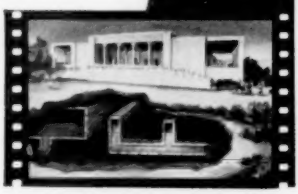
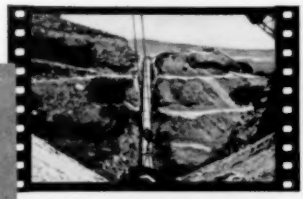


Water supply systems were constructed of stone and masonry nearly 6000 years ago by Persian engineers.

With the Dark Ages, advancements in water transportation were lost and water was supplied from communal wells.



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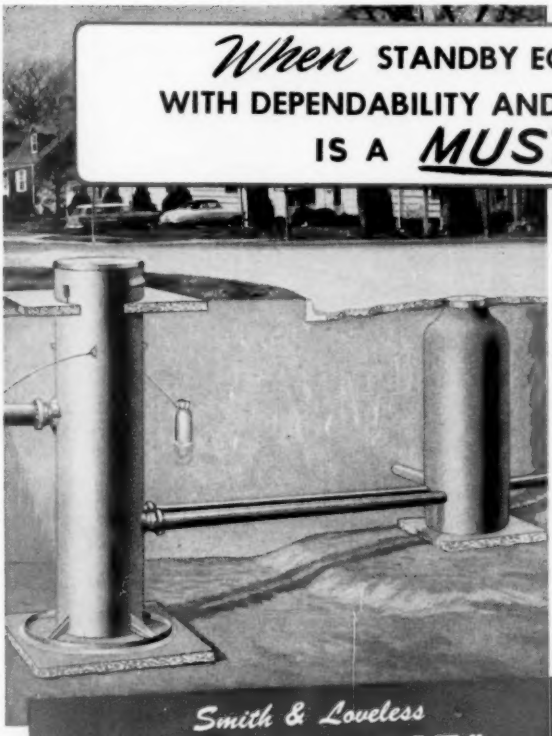

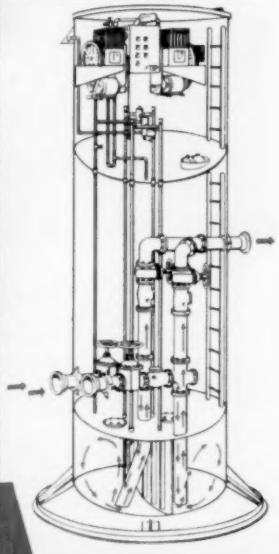

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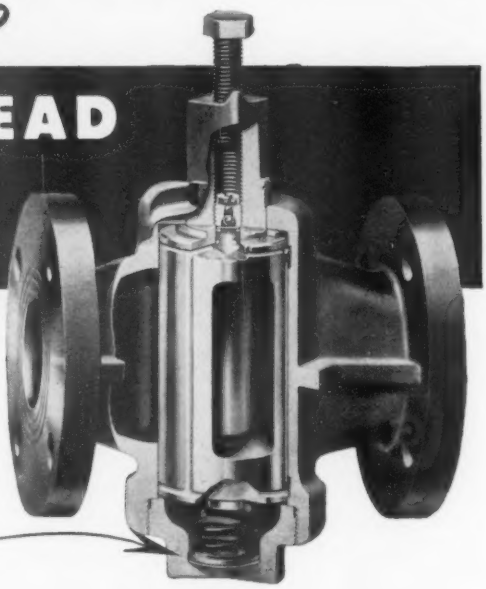

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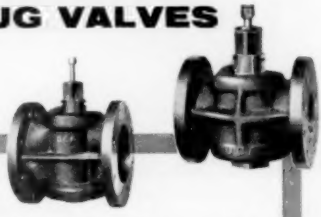

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SEWAGE AND INDUSTRIAL WASTES

Journal of the Federation of Sewage and Industrial Wastes Associations

Volume 29 | **July, 1957** | **Number 7**

Contents

1956 Literature Review

A Critical Review of the Literature of 1956 on Sewage, Waste Treatment, and Water Pollution. By FSIWA Committee on Research

Water Pollution 727

Sewage Works

Biochemical Oxidation of Various Particulate Fractions of Sewage. By J. L. Balmat 757

Solving the Sewerage Problem at Ukiah, California. By Roger F. Wilcox and Douglas S. Cruickshank 762

Aeration Requirements of a High Oxygen Demand Sewage. By Robert D. Bargman, Jack M. Betz, and William F. Garber 768

Discussion by Jack W. Pratt 789

Industrial Wastes

Underground Movement of Radioactive Wastes. By R. G. Orcutt, M. N. E. Rifai, G. Klein, and W. J. Kaufman 791

Water Conservation and Reclamation System for a Copper Wire Mill. By G. W. Pirk 805

Stream Pollution

Factors Affecting the Response of Fish to Toxic Materials. By Charles M. Weiss and James L. Botts 810

The Operator's Corner

Responsibilities of a Sewage Treatment Plant Operator. By Donald M. Pierce 819

A System for the Qualitative Analysis of Sewage Greases. By G. P. Gribkoff and S. J. Nakada 821

Interesting Extracts from Operation Reports: Greater Winnipeg, Man.; Omaha, Nebr.; Cincinnati, Ohio 826

Tips on Sludge Drying Bed Care. By Melvin Bowers 835

Tips and Quips 836

Editorial

Boston 1957 839

Reviews and Abstracts 840

Proceedings of Member Associations

Texas Water and Sewage Works Association 292a

Arizona Sewage and Water Works Association 296a

Missouri Water and Sewerage Conference 296a

Equipment and Supply Lines 298a

Ralph E. Fuhrman, *Editor*, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

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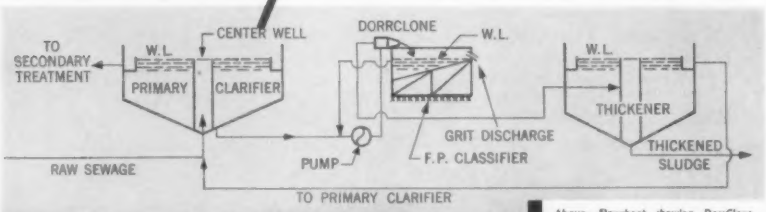
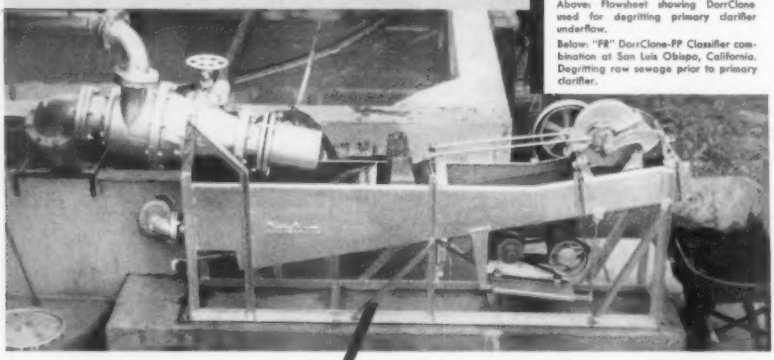


Above: Flowsheet showing DorrClone used for degritting primary clarifier underflow.

Below: "FR" DorrClone-FP Classifier combination at San Luis Obispo, California. Degritting raw sewage prior to primary clarifier.



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Full scale installations have proven that this unit is applicable to the degritting of raw sewage prior to primary sedimentation; the degritting of primary clarifier underflow prior to Densludge Thickening; and the washing of Detritor Collecting Tank discharge.

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1956 Literature Review

A REVIEW OF THE LITERATURE OF 1956 ON SEWAGE, WASTE TREATMENT, AND WATER POLLUTION

By H. Heukelekian, *Chairman*, R. Manganelli, *Vice-Chairman*, H. Amberg, R. A. Canham, W. E. Dobbins, G. P. Edwards, M. B. Ettinger, D. G. Foulke, T. DeS. Furman, I. Gellman, A. E. Griffin, H. G. Harding, R. D. Hoak, W. M. Ingram, P. W. Kabler, M. Katz, F. W. Kittrell, L. J. McCabe, P. H. McGauhey, W. A. Moore, P. K. Mueller, R. Porges, E. R. Roth, L. R. Setter, A. J. Steffen, C. M. Tarzwell, G. H. Teletzke, W. W. Towne, H. A. Trebler, E. C. Tsivoglou, and R. L. Woodward

Committee on Research, Federation of Sewage and Industrial Wastes Associations

This is the third of three sections of the review and deals with water pollution. The first section, dealing with analytical methods and sewage, was published in the May, 1957, issue of This Journal. The second section, dealing with industrial wastes and radioactivity, was published in the June, 1957, issue of This Journal.

WATER POLLUTION

Biology

Pollution Surveys

A survey of several rivers in India indicated damage to fisheries by wastes from chemical works, paper mills, sugar refineries, and by the discharge of sewage. Remedial measures have been suggested but there is no pollution legislation in India (24). In reporting upon a survey of Birmingham streams, Hawkes (72) points out that biological characteristics are of importance in determining the effects of a pollutant. The character of the stream community reflects the "effective" pollution and avoids the complications involved in strictly chemical or physical standards. The effect of pollution can range from a slight shift in the proportions among the natural population to a complete alteration of the entire range of life forms. He found that the biological method tends to give an average pollution indication, whereas chemical sampling gives only a "spot" result.

A survey of the upper Rhine (49) indicated that Lake Constance is of great importance in supplying well oxygenated water to the river. In spite of heavy pollution above the lake, the phytoplankton in the lake insure well aerated water. Downstream, conditions for the development of plankton become increasingly unfavorable due to increase in turbidity and decrease in D.O.

Surveys of environmental conditions in estuaries have shown that their capacity for self-purification is not as great as is commonly believed. Studies made in Wellington Harbor, New Zealand, showed that M.P.N. values alone are not satisfactory for surveys of an area where old sewage may be returned by wind and tide. It was found that wind is the dominant factor in the dispersion of the sewage and that tide plays only a minor part (90). Studies of the bottom materials of the lower San Gabriel River of California demonstrated the deposition of materials having either a sulfide or petroleum odor. No living organisms were noted in these deposits but, after cleaning by dredging, 12 species of marine invertebrates became established. However, within two years after excavation there was evidence of the formation of new deposits (142).

In connection with studies in British estuaries, Southgate and Gameson (160) propose two standards for the management of rivers. One would limit the concentration of particular constituents in an effluent, and the second would be a measure of the effect which the effluent would have on a river. These effects could be measured by bio-assays with fish, and B.O.D. studies. It is pointed out, however, that the normal 5-day B.O.D. test does not necessarily indicate the total effect of the effluent on the stream, as nitrification may occur shortly after discharge and the ratio of the ultimate oxygen demand to the 5-day B.O.D. varies widely. The rate at which oxygen is dissolved from the air also depends on the type of stream. Synthetic detergents markedly reduce the rate at which oxygen is absorbed from the air by deoxygenated water. It is recommended that in estuaries in which the dissolved oxygen approaches the critical level, remedial measures be undertaken before anaerobic conditions develop. Studies are now in progress on the anaerobic digestion of strong organic waste waters, such as those from slaughter houses.

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Fish Kills

The Aquatic Life Advisory Committee of the Ohio River Valley Sanitation Commission has prepared a booklet on procedures for the investigation of fish kills. Various possible causes of fish kills are discussed and methods for their investigation outlined. The importance of prompt investigation, thoroughness of coverage, and the use of biological indicators are stressed. The use and value of bio-assays for the determination of toxicity are also outlined (10).

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Stream Environments and Water Quality Criteria

The second progress report of the Aquatic Life Advisory Committee of ORSANCO (9) deals with temperature, dissolved solids, settleable solids, chloride, fluoride, color, and D.O. It is concluded that, for a well-rounded warm-water fish population in the Ohio River, peak water temperatures should not be raised above 93° F. at any time; during the period December through April, water temperatures should not be raised above 73° F.; and further, temperatures in streams suitable for trout should not be increased.

Bio-assays were recommended to determine the degree of dilution essential for the safe disposal of brines and other complex wastes high in dissolved solids. Due to lack of definite information, no criterion was formulated on the amount of settleable solids which could be added to a stream. It was pointed out, however, that the deposition of any material on a gravel rubble bottom reduces productivity. It was recommended that no organic wastes be added to streams in such quantities that they alone or in combination with inorganic material form sludge beds or change the physical nature of the bottom.

It was suggested that chloride ion concentration has in itself no practical significance as far as aquatic life is concerned. It was recommended that fluoride ion concentration be limited to levels found safe for human consumption. In regard to color, it was considered desirable to restrict the addition of any substance to natural waters that reduces the productivity of aquatic plants through lessening of light penetration.

Suspended Solids and Turbidity

In Europe, many industries discharge turbid wastes into streams with resulting turbidity and the blanketing of the stream bottom. Among these are dusts and inorganic wastes from metalworking and mining industries, iron-ore-crushing plants, blast furnaces, rolling mills, talc and magnesium plants, and coal mines. The iron-ore-crushing plant at Erzberg-Eisenerz has a waste containing 5,000 p.p.m. suspended solids, while coal and lignite washings from mines have 1,000 to 5,000 p.p.m. These wastes blanket the stream bottom and destroy food producing areas (165). During the war, when industry was shut down, the streams cleared up and recovered.

The rivers Mur and Murz in Styria are heavily polluted with industrial waste waters. Wastes are of two types, those from iron and mining. One of the most damaging materials is fine clay, which is not removed in the settling pits and damages the turbines of power works downstream. Materials which settle out make the bed of the stream almost sterile. In addition, $Fe(OH)_3$ from pickling wastes is precipitated on the eggs and gills of fishes with lethal results. Waste waters from mining and the treatment of iron ore produce turbidity over long stretches of stream (166).

Studies made in Mill Creek, a tributary of the Sacramento River, indicated that a severe loss of king salmon eggs occurs during incubation due to silt and stream erosion (59). Eggs placed in a channel free from silt had a survival rate four times as high as those subject to silting (60).

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Temperature

Studies carried out at the Hunt Creek Fisheries Experiment Station in Michigan have shown that impoundment by a beaver dam raises the water temperature significantly. When the average water temperatures for the three years previous to impoundment were compared with those for the three years following impoundment, it was found that the average temperature had increased 10.1° F. for June, 8.8° F. for July, and 6.5° F. for August (154).

Results of acclimation tests indicated that the upper tolerance temperature for a species depends to some extent on the temperature to which it is acclimated. Channel catfish acclimated at 22° C. died a few hours after exposure to 35° C.; while those acclimated at 30° C. were all alive after 24 hr. of exposure to 35° C. Under conditions of continuous exposure, channel catfish died at 32° to 33° C. Bullheads survived temperatures of 34° C. It is suggested that most temperate zone streams should not be raised above 30° C. for prolonged periods (21).

In all fish studied, the upper lethal temperature was below 40° C. regardless of acclimation. High temperatures decrease resistance to toxic materials. Because there is severe competition for space, a species may be eliminated by an unfavorable but not lethal temperature. Thus, optimal temperatures should be of more concern than those of bare survival. Variations of 4° C. in either direction from the optimal 26° C. will slow growth of *Nitzchia filiformis* (22). Other species have an even narrower range of tolerance.

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Dissolved Solids and pH

Drainage from strip-mining slag piles was found to be lethal to fish in dilutions of 1 in 50 (111). Acid in the drainage from mines is produced by bacteria in the presence of air and water (169).

A survey of three strip-mine areas in southern Illinois under both summer and winter conditions indicated no relation between age and the condition of the water, at least between the ages of 4 and 30 years. The majority of the ponds were slightly basic, but some were extremely acid. The most common fish found in the ponds were green sunfish, bluegill, and largemouth bass. Many ponds were devoid of fish, and it was concluded that possibilities for the production of fish in strip-mine ponds are limited. This is due to acidity, high salt content, and low fertility (112).

Studies of the median toxicity thresholds of 10 fresh-water fishes to oil-well brines indicated a range in the values from 4.3 to 11.2 per cent of the brine from a single well. Median toxicity thresholds for 10 invertebrates ranged from 1.8 to 8.7 per cent of the brine (33).

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Dissolved Oxygen

Experiments carried out in a spring near Welaka, Fla., showed that *Gambusia* and *Mollienesia* could not survive at a D.O. level of 0.3 p.p.m., unless they were allowed to gulp air at the surface (132). It was found that while young sturgeon can live and grow at D.O. concentrations below 5 to 5.5 p.p.m. at 18° C., oxygen concentrations of that amount and above are required for optimum growth (118).

Studies of six fishes from Uganda showed that the hemoglobin of the blood of different species varied in its ability to take up oxygen at different levels of oxygen saturation and at different carbon dioxide concentrations. The hemoglobin of *Tilapia esculenta* shows considerable affinity for oxygen which allows that fish to survive under conditions which would cause severe respiratory distress in others (57). For young sturgeon 1.5 to 7 months old, the critical oxygen level, *i.e.*, the concentration below which oxygen uptake decreases, varied from 1.8 p.p.m. at 11° C. to 6.0 p.p.m. at 28° C. Threshold concentration, that is, the level at which oxygen uptake fell to zero, varied from 1.4 p.p.m. to 3.1 p.p.m. over the same temperature range (117).

A survey of environmental conditions in Osborn Bay near Crofton, Vancouver Island, B. C., showed that surface discharge of the pulp mill effluent inshore would result in oxygen levels too low for a healthy oyster population. It was recommended that the effluent be discharged at a depth of 10 fathoms and far enough outside the bay to allow adequate dilution and dispersal by strong currents (177). Studies on the Main and Danube rivers throughout the year indicated that the effects of putrefiable wastes on D.O. levels were less in free-flowing than in impounded stretches of the rivers, but reduced D.O. levels extended over a greater distance in the flowing stream (2).

Studies of polluted pools containing plant life showed that frequently the magnitude of photosynthetic reaeration equals or exceeds that produced by atmospheric contact. The photosynthetic factor can be very high in small rivers. The oxygen balance is calculated from data on daily level of dissolved oxygen only if the amount of dissolved oxygen in the whole water column is known and its variation throughout the day can be determined. Calculations based on purely locally drawn samples are unsatisfactory (176).

Death of fish in the Fox River was attributed to the presence of algae by an anonymous author. It was stated that the D.O. level fell from 3.05 p.p.m. at 6:00 P.M. to 0.4 p.p.m. at 6:00 A.M., and on the following day rose again to 3.3 p.p.m. (3) The author overlooked the fact that organic pollution is generally the cause of excess algal growth, that bacteria as well as algae respire at night, and that without the photosynthetic activity of the algae, D.O. levels would be low, both day and night. Further, if the photosynthetic activity of an excess population of algae cannot raise the D.O. content above 3.3 p.p.m., it is evidence that there is a great putrescible waste load being broken down by bacteria.

Laboratory experiments have indicated that the presence of anionic synthetic detergents reduce the rate of solution of oxygen through the surface. Experiments were made in a stream and it was concluded that detergents reduce the rate of entry of oxygen into the water (174).

Lac de Bret, originally oligotrophic, has undergone a steady eutrophication with a well developed thermocline and a long-continued stagnant hypolimnion during the summer months. Artificial sub-lacustral aeration added 9 to 10 metric tons of oxygen to the hypolimnion and removed 8 to 9 tons of carbon dioxide and thus reduced productivity so that eutrophication was arrested.

This removed the iron problem in the water supply and brought about a change in the plankton (125). It was found that the toxicity of non-ionized ammonia increased as the D.O. content decreased. Further, a solution containing ammonia and synthetic detergents was more toxic than solutions containing each of the two substances individually. A concentration of non-ionized ammonia equivalent to 0.2 p.p.m. nitrogen decreased the survival time of trout at a D.O. level which otherwise had no lethal effect. There was also a definite interaction between dissolved oxygen and carbon dioxide (75).

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Toxicity

Studies of the toxicity of 9 inorganic salts to *Daphnia magna* clearly indicated that a reduction in the D.O. level below 4.5 p.p.m. reduced the resistance of the daphnia to the toxic materials (56). The Fish and Wildlife Service Laboratory at Kearneysville, W. Va., made toxicity screening tests with 735 compounds made available by the Chemical-Biological Coordination Center. Tests were made in constant temperature aquaria at concentrations of 5 p.p.m. with brown trout, bluegill, yellow perch, and goldfish. Times for sickness or death are listed in hours (107).

Bio-assays are now being used not only to determine the toxicity of materials but also to determine the quantity of a toxicant present or to detect its presence in very small quantities which cannot be determined chemically. Shaw and Lawrance (153) used bio-assays for the estimation of metal ions. They prepared progressively diluted aliquots of an unknown solution containing the cation to be estimated. Then the toxicity of these aliquots for the test organism (guppies) was compared with the toxicity of standard solutions containing the same cation and the concentration of the unknown calculated. This procedure approaches the accuracy of the most refined chemical techniques and allows a great saving in time and cost. A similar technique has been used for the quantitative estimation of the molluscicide, sodium pentachlorophenate, in natural waters. The test requires evaluation of mortality rate curves for specific dosages covering the range of conditions to be encountered in the field. Quantitative field determinations are obtained from a comparison of the unknown with the standard mortality curves. This method gives reliable results necessary for effective molluscicide operations (96).

Another approach to the toxicity problem has been proposed by Halsband and Halsband (68). They believe that the effects of poisons and waste waters on fish should not be measured by the death or overturning of fish in aquaria

but by the pathological effects. Using the method with trout, the boundary for phenol was 1.3 p.p.m. Greven (65) reviewed the methods for determining the effects of toxicants on fishes and tested several methods. He discussed the expression of results used by different workers and recommended that lethal limit be defined as the concentration which causes death of a given type of fish within 24 hr.

According to an account given by Czerkinski (39), extensive studies are under way in Russia for determining the permissible concentration of toxic and other harmful materials in surface waters. Thirteen investigators examined 30 toxic and otherwise harmful materials and presented tables listing permissible concentrations and decisive tests. The standards proposed have been adopted as legally binding.

Metals

In most previous investigations, the toxicity of iron has not been adequately separated from the effect of the low pH brought about by the iron salts. La Roze (101) has attempted to overcome this difficulty in his studies by using iron lactate. He was able to observe in very low concentrations of iron, the entrance of the iron into the fish gills. There appeared to be no resistance to the entrance of iron in the cation form but anionic iron penetrates only after death, and, therefore, does not have a toxic action. Death does not occur before about 2 hr., regardless of the concentration of iron. If before this time the fish are placed in pure water, the iron leaves the gills. Poisoning by iron is a reversible phenomenon which can be explained by an impregnation of the gills. With solutions containing 1 p.p.m. iron, it can be removed in 8 hr.; for 2 p.p.m. the period is 12 hr.

Studies of the toxicity of copper sodium citrate, $HgCl_2$, HgI_2, and ethylmercuric chloride to the crustaceans ***Artemia salina, Elminius modestus,*** and ***Acartia clausi,*** indicate that ***Artemia*** is the most resistant. Differences in resistance were also greatest for ***Artemia.*** Mixtures of the copper salt and $HgCl_2$ showed more than additive toxic effects. ***Artemia*** exposed to sublethal doses of copper are rendered more susceptible to poisoning by the mercury salts. The reverse is also true (36).

Saitzeva reports (146) that his experiments are in agreement with the suggested maximum limit of 0.1 mg. of lead per liter in water supplies for consumption. There is also a suggested limit for fishes in some waters. Experiments have indicated that concentrations of less than 20 p.p.m. CrO_4 prevent multiplication of sulfate-reducing bacteria, but that they have a bacteriostatic rather than a bactericidal action (48).

Studies carried out by the Washington Department of Fisheries Laboratory have indicated the relative toxicity of several metals in fresh and salt water. Minimum lethal concentrations in parts per million of the following were found to be: $BaCl_2$, 148 p.p.m.; hexavalent chromium, less than 10 p.p.m. in fresh water, 17.8 p.p.m. in sea water; trivalent chromium, 50.0 p.p.m. in fresh water, more than 50.0 p.p.m. in sea water; Cu $(NO_3)_2$, 0.18 p.p.m. as copper in fresh water, and 0.56 p.p.m. as copper in salt water; and lead acetate, 2.8 p.p.m. as lead in fresh water (63). It should be realized that these results are applicable only for the particular dilution water used.

The effects of $MnCl_2$ and $MnSO_4$ on fish, crabs and fish food organisms were determined by means of bio-assays. With $MnSO_4$ the first adverse effects were noted at a concentration of 500 p.p.m. and death occurred at 1,000 p.p.m. With $MnCl_2$ the first effects were observed at 333 p.p.m., whereas a concentration of 400 p.p.m. produced death. Sphaerium, dragonfly larvae and ***Cambarus affinis*** were apparently undamaged at concentrations of 1,000

p.p.m. (119). In studies to determine the toxicity of magnesium salts to guppies and *Tilapia macrocephala*, it was found that resistance increased with age. For guppies the toxicity threshold was 8,000 p.p.m. in the dilution water used, while for *Tilapia*, it was 1,000 p.p.m. (7).

Cyanide

Complexing has been suggested as a method for the disposal of cyanides. In some instances this may be helpful but in others it is not. Zinc cyanide and cadmium cyanide complexes proved to be exceedingly toxic. Synergism of the toxic metallic ions and cyanide liberated through dissociation of the complex ions is indicated. The combination of nickel and cyanide into a complex resulted in a marked reduction of the toxicity of each. Concentration of free cyanide only, in undiluted cyanide-bearing waste waters, is not a reliable measure of the pollutional potency of the waste. Metal-cyanide complex ions, including the relatively stable nickelo-cyanide ion, must be regarded as potential sources of toxic HCN (45). It has been shown that, in concentrations of KCN between 0.07 and 0.25 p.p.m., the log period of survival of rainbow trout decreased linearly with increases in log concentration of poison (74).

In discussing the cyanide problem in Britain, Pettet and Ware (137) state that the toxic effect on fish of a cyanide concentration above 0.018 to 0.025 p.p.m. precludes the discharge of waste waters containing cyanide in inland watercourses.

Phenol

Phenolic waste waters cause loss of fish due to the removal of oxygen from the water, the repelling of the fish, toxic action, the tainting of fish flesh, and the destruction of food organisms (12). It has been found that phenol kills Tubifex worms at a minimum concentration of 200 mg. per liter, but 150 mg. per liter were not lethal in 5 days (66).

Studies in Germany indicated that the various phenols in combination have an additive effect but generally they do not occur in concentrations lethal to fishes. Among the substances tested para-xylenol was the most toxic (18). Several of the phenolic compounds cause the tainting of fish flesh at concentrations far below those lethal to fishes. Chlorophenol is especially bad for the tainting of fish flesh. It is concentrated in the fatty tissue of fish and oysters and, while man can detect it at 1 part in 100 million, these animals can acquire noticeable tastes from waters containing as little as 1 part in 10^9 parts of water (14).

Ammonia

Investigations directed toward obtaining information on the effects of the concentration of dissolved oxygen on the toxicity of ammonia were carried out at D.O. concentrations of 1.0 to 9.0 p.p.m. Solutions containing un-ionized ammonia equivalent to 1.96, 1.38, and 0.86 p.p.m. nitrogen were used at a pH of 7 to 8 and a temperature of 19.8° C. Results showed that the periods of survival of trout increased as the D.O. concentrations increased, that at each D.O. concentration the period of survival decreased as the concentration of un-ionized ammonia increased, and that the effect of oxygen in increasing survival time was greatest in the lower concentrations of un-ionized ammonia (47).

Detergents

The British Committee on synthetic detergents (143) concluded that the anionic surfactant now in greatest use does not appear to be readily or completely destroyed by existing sewage treatment methods; that rivers receiving these effluents are adversely affected with respect to their ability to support healthy fish and plant life, and their suitability for drinking water.

Studies were made of the toxicity of synthetic detergents to fishes with special reference to the substances in the commercial products other than the surface active agents. It was found that the following had little or a low level of toxicity: sodium sulfate, sodium silicate, sodium tripolyphosphate, sodium pyrophosphate, and sodium perborate. A fatty alkylamid killed all fish in 24 hr. at a concentration of 24 p.p.m. (8).

Studies made by Mann (121) indicated the detergents act on the epithelium of the gills and skin. No tainting of the flesh was noted. Tests were also made with Leonil AR, an anionic-active product on an alkylaryl sulfonate basis, on fish-food organisms, Tubifex, *Chironomus, Carinogammus,* and *Asellus.* Tubifex was most resistant and Chironomids most sensitive. Detergents were toxic at concentrations of 10 to 25 mg. per liter. Concentrations up to 10.7 mg. per liter have been found in crude sewage. Therefore, the effects on the aquatic fauna must be considered.

Oil Refinery Wastes

Investigation of a stream receiving oil refinery wastes indicated that the typical color and odor of the effluent persisted as far as 18 miles downstream where the dilution was twenty-fold. The dissolved oxygen was eliminated in the stream. The number of species of aquatic organisms recorded was 32 above the refinery and 11 below (32). Experiments with different chemicals occurring in oil refinery waste waters have shown that many of them can clarify turbid waters characteristic of the southwest. Some clarified the water at levels which were non-toxic to fishes but the required levels for others were toxic (180).

Paper Mill Wastes

The avoidance reactions of juvenile chinook salmon and coho salmon to waste from sulfate and sulfite process pulp mills, and the reaction of steelhead trout to sulfate waste were investigated by means of a modified gradient tank. Chinook salmon showed marked avoidance of sulfate waste; coho salmon showed much less avoidance; and steelhead trout showed none. Chinook salmon showed avoidance of 10, 5, and 2.5 per cent of the waste in dilution water. Coho showed little avoidance of waters containing 10 per cent of the waste (91).

Bio-assays of cellulose waste waters showed that a dilution of 1 part waste in 800 parts water was lethal to goldfish in 24 hr. A dilution of 1 in 2,000 caused discoloration of the skin and, for safety, a dilution of 1 in 3,000 was chosen. When the waste water was neutralized, the toxic material was precipitated (94). The toxicity of the waste water from the sulfite cellulose plant was also determined for the algae, *Scenedesmus obliquus.* The most toxic component of the waste was identified as pitch abietic acid (95).

Insecticides

Bio-assays were conducted to determine the toxicity to rainbow trout of seven insecticides; chlordane, heptachlor, aldrin, dieldrin, toxaphene, methoxychlor, and DDT. They were tested as emulsions, wettable powders, and dusts. Fish were exposed for 24 hr. to concentrations of 0.05, 0.1, 0.25, 0.5, and 1 p.p.m. of the various materials. Toxaphene and dieldrin were the most toxic, while chlordane and DDT were generally least toxic (123).

Two barge loads of chlorinated hydrocarbons were dumped in 100 fathoms of water about 100 miles south of Galveston. Bacterial counts showed little injury to bacterial populations, but blue-green algal photosynthesis was inhibited. Zooplankton studies did not show excess toxicity, but the sea anemones were affected (84). Freshwater animals on the Island of Cyprus have been devastated by DDT spraying for the eradication of mosquitoes (163).

Advances in chemical technology have resulted in the development of over 100 effective insecticides. These materials fall roughly into two groups, namely, the chlorinated hydrocarbons and the organic phosphates. The former are most stable, retain their toxicity over much longer periods, and are far more lethal to fish. Golden shiners are among the most resistant fishes to insecticides, while bluegills, largemouth bass, and goldfish show increasing sensitivity in the order named. TDE and BHC are the safest of the chlorinated hydrocarbons for the fishes. Crustacea and many of the aquatic insects are more sensitive than fish, while mollusks are more resistant. Generally, dieldrin, toxaphene, heptachlor, aldrin, endrin, and methoxychlor are more toxic to fish than DDT or chlordane, while EPN, BHC, and TDE are less toxic, with TDE and BHC being the least toxic. However, BHC causes the tainting of fish flesh when used at concentrations of 1 lb. per acre (161). A bibliography of references on the harmful effects of insecticides, algicides, and herbicides to aquatic organisms, other than those they were designed to control, has been prepared by Ingram and Tarzwell (88).

The toxicity of rotenone to yellow perch was studied under laboratory conditions and toxicity curves were constructed. This fish is killed at low concentrations as is the brown trout (20). Pentachlorophenate used as a molluscicide for the control of the snail hosts of schistosomes is quite toxic to fishes at concentrations as low as 6 p.p.m. Aquatic insects of importance as fish food are also killed (97).

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Putrescible Wastes

Effects of Organic Enrichment

An investigation of the effects of the discharge of large volumes of treated

sewage to a lake near Copenhagen, Denmark, indicated that it resulted in the production of a large amount of phytoplankton. In July, almost 10 g. of carbohydrates were produced per square meter per day (129). In a study of Lytle Creek, it was found that the length of the creek chubs, *Semotilus a. atromaculatus*, of the same year class, differed significantly in the various pollutional zones. They were smallest in the stretch of stream above the sewage outfall and largest in the lower portion of the recovery zone, the difference being about 20 per cent (93).

An investigation of the behavior and relation of nutrient materials in oligotrophic and eutrophic lakes lead to the conclusion that in oligotrophic lakes little nutrient matter returns from the sediment, while in eutrophic lakes a much greater part of the nutrient matter returns to solution. Nitrogen compounds are redissolved in much greater quantities than phosphorus compounds and thus, the addition of a waste rich in phosphorus may suddenly convert an oligotrophic lake into the eutrophic type (172).

Lake Washington has been receiving increasing amounts of treated sewage and appears to be responding by changes in kind and quantity of biota. There has been an increase in the oxygen deficit in the hypolimnion and an increase in the phosphate concentration (50). As shown by other investigators (159), the concentration of minerals present in sewage-works effluents can cause excessive algal blooms in lakes. It is suggested that the nutrient materials be removed from the lake in the form of algae which can be used as fertilizer.

Laboratory experiments indicated that a continuous discharge of spent sulfite liquor was most favorable for optimum growth of *Sphaerotilus natans*. In order to control or reduce *Sphaerotilus* growths in the river, intermittent discharge of spent sulfite liquor was initiated with a discharge interval of less than 6 hr. It was thought that this reduced the growths in the river (1).

The soluble phosphates in the effluent from a secondary treatment were found to supply ample nutrients for the growth of algal blooms in Lake Zoar, Conn. There was a succession of different dominant species as the seasons progressed: *Oscillatoria, Microcystis, Anabaena, Spirogyra,* and *Hydrodictyon* (38). The critical concentration of phosphorus for blue-green algae is stated to be 0.01 p.p.m.

Indicators of Organic Enrichment

In a study of the Elbe River from the outlet of the Hamburg harbor region to Kugelbake, it was found that the degree of pollution was clearly recognizable by the communities of organisms present (11). In general, those organisms most favored by a given environment will be most numerous while those adapted or adaptable to the widest environmental range will occur in the greatest number of samples. The species found in greatest number probably indicate a response to some particular characteristic of the environment. Specific meanings of various populations are listed by Lackey (99).

A modification of the commonly recognized life zones in polluted streams has been suggested by Sramek-Husek. It is to divide the polysaprobic zone of Kolkwitz and Marsson into four groups, one or all of which may not be present in a particular stream. These are: (a) antisaprobic, an area of high concentration of toxic industrial wastes and all life absent; (b) hypersaprobic, an area of highly fermentable fresh wastes, B.O.D. of 500 p.p.m. or above, and biota characterized by great masses of yeasts; (c) a-polysaprobic, a zone with B.O.D. between 100 and 500 p.p.m. and biota of bacteria and achromatic flagellates; and (d) B-polysaprobic, an area characterized by a B.O.D. between 10 and 100 p.p.m. and a biota

consisting of *Sphaerotilus*, polysaprobic flagellates, Tubifex, some *Chironomidae*, and *Eristalis* (162).

Many springs in Florida are deficient in dissolved oxygen. Oxygenation is rapid, but definite zones are established in which organisms are found in accordance with their dissolved oxygen preference or requirements. Forms generally considered as tolerant of organic enrichment are found in the spring heads (157).

Seibold investigated the effects of certain sewage decomposition products in *Planaria*, oligochaetes, leeches, and insect larvae. In these studies which continued for as long as 21 days, indole, skatol, histamine, putrescine, cadaverine, and hydroxylamine were used. It was found that skatol, indole, and hydroxylamine were most toxic, while histamine, putrescine, and cadaverine were less toxic, being harmful at levels of about 30 p.p.m. These materials are more lethal at higher temperatures. The degree of sensitivity of the various aquatic organisms is related to their rank in the saprobic system (150).

In studies of the effects of sewage pollution on Lytle Creek, chemical and physical conditions were related to the qualitative and quantitative composition of the aquatic populations found in the different "pollutional zones." It is pointed out that little reliance can be placed on any one species as an indicator of organic enrichment. It was found that in clean waters there was a great variety of organisms, usually gilled forms, none of which occurred in great abundance. In the recovery zone there were fewer species, usually those having several methods or organs for respiration. In the septic zone the population was represented by only a few species, but by large numbers of individuals, all of which were adapted in one way or another to survive at very low D.O. levels (62).

In Louisiana, it was found that studies of aquatic populations were essential for determining the pollutional status of some streams. It was observed that the aquatic populations were indicative of the pollutional zones (34).

A total of 94 species of Diptera were collected from Lytle Creek in southwest Ohio (134). Diptera are found in many different environmental niches in both clean and organically enriched water, and many are highly selective in their habitat preference. Those species with special adaptations for obtaining oxygen from the water surface, such as the larvae of the families *Culicidae*, *Syrphidae*, and *Stratiomyidae*, occurred frequently in large numbers in the septic and recovery zones. Representatives of the family *Chironomidae* are adapted to many different habitats in the stream, with several species showing a marked selection for specific environmental niches in each of the life zones. The presence of *Chironomus riparius*, *Glyptotendipes* sp., *Eristalis bastardi*, and *Culex pipiens* in large numbers was characteristic of the septic and upper recovery zones, and their abundance in other similar streams may be interpreted as an indication of organic enrichment. Species restricted to definite and narrow habitats constitute much better indicators than those species adaptable to a range of conditions. Clean-water species are in general more reliable indicators of environmental conditions.

Comparative studies (98) of three streams gave evidence that quantitative and qualitative determinations of the suspended algae and protozoa provide specific evidence of the fertilizing effects of a treated sewage effluent. Recent fecal pollution appears to be a factor favorable to stimulating blooms of certain species of *Euglenophyceae*, while the same environment appears to be limiting for some species of *Chrysophyceae*.

Brondyke (17) states that careful study of a stream's diatom population and their distribution gives a reliable

criterion of the water's ability to support aquatic life. The Sabine River was surveyed by the use of a "diatometer," and improved pollution control methods were based on the results obtained.

Effects of Impoundment

The amount of self-purification is an essential point in assessing the quality of stream water. Damming a stream alters the original population including the fish life. In streams of good condition, dams do not have an adverse effect on self-purification. Heavy pollution, however, has a great effect on the condition of the water (113). The construction of large dams in the Tennessee Valley has caused major environmental changes in the streams below the dams, including lower average temperatures, erratic seasonal D.O. patterns, and great daily fluctuations in water velocity and volume (138).

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Microbiology

In 1955, water was definitely incriminated in only two disease outbreaks in this country (42). One outbreak affected fire fighters who filled canteens from water tanks previously used to pump cesspools. All continued their duties. The other outbreak was in a school where 22 were ill. The water supply was from a well contaminated by a septic tank and *E. coli* was recovered from the well water.

One large outbreak of infectious hepatitis including over 7,000 cases occurred in New Delhi, India (41) and was attributed to the treated municipal water supply which was heavily contaminated with sewage before treatment. Another small outbreak of infectious hepatitis occurred in Austria (135).

LeMaistre *et al.* (106) reported the epidemiological aspects of a waterborne outbreak of amebiasis that occurred in South Bend, Indiana in 1955. A membrane filter procedure for the demonstration of *E. histolytica* in contaminated water was described by Chang and Kabler (26). By this method, 50 per cent positive cultures were obtained from 1-gal. samples if the initial cyst concentration was five cysts per gallon. Observations on the survival of *Shigellae* in sewage (181), of *Leptospira australis* in soil and water (158), of human tubercle bacilli in polluted waters (77)(78), and of Coxsackie virus (30) in water and sewage clearly demonstrated that all these organisms survive for considerable time in polluted waters and must be considered in water treatment practice.

Stevenson *et al.* (164) developed a method of concentrating dilute virus suspensions by alum flocculation which detected as little as about 0.006 LD_{50} per 0.02 ml. of original sample.

Metzler, Ritter, and Culp (126) showed the combined process of plain sedimentation, coagulation, settling and rapid sand filtration, as practiced in conventional water treatment plants, completely removed all viable spores of *H. capsulatum,* even without chlorination.

Cooke, Moore and Kabler (35) studied eight species of fungi, commonly isolated from sewage, that were able to compete successfully with other microorganisms for organic materials in solution and for oxygen available in the dissolved state. Significant reductions in dissolved oxygen were observed in the first four days at pH 2.9.

The physical, chemical, and biological composition of submerged slime growths in sewage and polluted waters were discussed by Heukelekian and Crosby (79)(80). They also studied effects of environmental conditions on slime formations.

Joseph (92) described taste and odors and a purplish pink color in a service reservoir that were caused by a colored sulfur bacterium identified as *Rhodocapsa* species. It was assumed that gulls feeding at the sewage works and resting on the reservoir at night were responsible.

The role of *Ferrobacillus ferrooxidans* in stream recovery from acid bituminous coal mine wastes was reported by Leathen *et al.* (103). Eventually the iron was deposited as a brownish yellow sludge in the stream, while the stream itself remained acid.

Enteric organisms in sea water and tidal estuaries (133)(64)(130)(16)(90)(188) usually suffer high mortalities in the first few hours, but a few cells may survive a month or more. Interactions of salinity, sedimentation, predation by higher forms, sunlight, bacteriophage, biological activity, etc., contribute to bacterial deaths. The comparative viability of pathogens appears similar to nonpathogens; however, this relationship is still not adequately defined.

Peso and Mignone (136) and Ware and Mellon (182) did not find bacteriophage a useful indicator of water pollution. Willis (186)(187) concluded that anaerobes do not provide a useful index of fecal pollution of water because they are widely distributed in soil and that many of the anaerobes found in water are derived from the soil.

Symons (167) discussed physical and chemical disinfectants, the disinfection reaction and factors influencing the reaction. In comparison of ozone and chlorine as water disinfectants, Hann (69) reported that ozone was more effective when applied in similar

dosages. Using radioactive chlorine, Friberg (58) found 10 to 25 per cent of the free available chlorine used was in the bacterial cells after 5 min. exposure to 0.5 p.p.m. free available chlorine. No significant difference was demonstrated in the amount of free chlorine absorbed by *E. coli* and *Staph. aureus*. Heicken (73) described the chemical reactions occurring in chlorination of sewage, the hydrolysis equilibrium and the reactions of chlorine with ammonium. There was no linear connection between oxidation potential and bactericidal action.

Clarke, Stevenson and Kabler (31) showed that purified type three adenovirus was inactivated by chlorine in amounts similar to that required for inactivation of *E. coli* and *S. typhosa*. Chambon and Vigne (25) considered chlorination the only practical means of sterilizing sewage from hospitals for infectious diseases. For complete sterilization it was necessary to allow contact for 2 hr. and 20 min. with 56 mg. of chlorine per liter. Lowe *et al.* (116) reported the destruction of microorganisms in polluted water, sewage and sewage sludge by ionizing radiations in dosages from 7.5×10^4 to 2.0×10^6 rad. No correlation between the physical strength of various bacterial cells and their susceptibility to the lethal effect of freezing could be demonstrated (173) (70).

Differential bile-salt tests at 44° C. for the detection of fecal contamination in water was found more rapid and convenient by Buczowska (19) than conventional lactose fermentation tests. Emmenegger (52) preferred formatericinoleate medium over MacConkey medium for testing river water for the presence of *E. coli*. Of the various antibiotics tested by Dianova and Voroshilova (44), gramicidin C. and streptomycin were the most satisfactory for the isolation of typhoid and dysentery organisms from river water.

In testing Potomac River water, Gunther and Fisher (67) secured higher coliform counts in lauryl sulfate broth containing 10 units of penicillin per 5 ml. of broth than without penicillin. They stated that the penicillin stimulated the growth of coliform organisms and inhibited growth of many other forms. Shipe and Fields (155) suggested the use of a chelating agent, tetrasodium salt of ethylenediamine tetraacetic acid, for maintaining the coliform index in water samples during transportation from collection site to the laboratory.

In considering methods of reporting coliform density, Hopkins and Schamberger (86) found the geometric mean more desirable for comparing bacterial characteristics of one stream with another, and in comparing conditions in one stream from month to month and year to year. Walton (179) presented data showing that adequately designed and well-operated water treatment plants can treat raw waters heavily laden with coliform organisms to produce effluents conforming to the bacteriological requirements of USPHS drinking water standards. These results indicate that current USPHS recommendations with respect to the density of coliform organisms in raw waters acceptable for treatment are no longer applicable in modern well operated plants.

Ritter, Shull, and Quinley (144) showed a positive association between coliform and enterococcus groups in well waters in Kansas, and that tests for enterococci would be useful in addition to tests for coliform organisms. Dardanoni (40) has confirmed the usefulness of azide medium for the isolation of enterococci from polluted and potable waters.

Macris (120) has proposed a rapid nitrite test for use in estimating the number of coliform organisms in water. Rawn and Bowerman (140) have summarized the advantages and disadvantages of the membrane filter (MF) test for coliform organisms in water and Enslow (53) and Eliassen (51)

have pointed out its potential as a water control method and suggested its use as an alternate standard. Thomas *et al.* (171) have reiterated these recommendations and proposed a code to be used with membrane filter results. Hope and Neill (85) demonstrated the feasibility of using membrane filter field test laboratories in determining the bacteriological quality of drinking water supplies in national parks. Hirsch (81) reported that membrane filter procedures were highly accurate and time saving in clearance testing of new pipelines. Additional information on the effects of media, temperature, and humidity on the development of coliform organisms by membrane filter technics has been reported by Eye, Gardner, and Neel (55). McCarthy (124) concluded that discrepancies between membrane filter and tube technics appeared to increase with time and distance from fresh pollution and that difficulties of recovery increased with ratio of noncoliform to coliform organisms. Using a combined method of membrane filtration and electronmicroscopy, Scarce (148) observed 68 to 75 per cent correlation of electron microscope readings and standard methods M.P.N.

Levin *et al.* (110)(109) have developed a radioisotope technic for the rapid detection of coliform organisms. A water sample was filtered on a ½-in. membrane filter using a syringe adapter. The filter was placed in a planchet with 0.1 ml. of C^{14} lactose. The planchet was placed in an apparatus and aerated, thus collecting radioactive carbon dioxide as barium carbonate. The emissions of carbon dioxide were counted in a modified Robinson gas-flow counter with a commercially available scaler equipped with amplifier. Positive results have been obtained from small numbers of coliform organisms after as little incubation as 10 min. and a total elapsed time of 25 min. Because of several unexplained biological vagaries, more developmental research is needed.

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Chemistry

Toxicological items of interest are reported here largely because they may not fit in under other headings of this review. Decker *et al.* (43) made a preliminary report on the effects of 0.1 to 10 p.p.m. of cadmium and 1 to 25 p.p.m. of chromate (as chromate ion) on animals. Possible adverse effects were noted only with 25 p.p.m. of chromate. These preliminary results

are held to be tentative pending completion of long time exposure tests. Cass (23) discussed the philosophy of approach and the proposed program of the ORSANCO-Kettering Water Toxicity Project.

The interaction of complex self-purification mechanics and water quality was considered in a number of papers. Skopintsev and Krylova (156) studied the stabilization of a "water humus" added to river water in the form of planktonic organisms. In 160 days the complex organic matter was largely destroyed or reduced to inorganic carbon. Bogan and Sawyer (15) made further report on the interrelationship of chemical structures and susceptibility to biochemical oxidation. Vinberg (176) discussed the oxygen balance in photosynthetic systems and enumerated the many variables involved in studying oxygen relationships therein.

Huet *et al.* (87) studied oxygen transformations in the Hain and Geer rivers, including consideration of photosynthesis in their studies.

Ettinger (54) discussed biochemical stabilization mechanisms and stressed the importance of the chemicals resistant to biochemical stabilization in determining stream water quality. Middleton *et al.* (127) presented data on the interrelationships of organic pollutants and the taste and odor problems in processed drinking water at Nitro, W. Va., which uses Kanawha River water a few miles below the chemical producing area at Charleston, W. Va.

Schmidt (149) presented an exhaustive study of the contamination of ground water by nitrates in Minnesota. In general, the high nitrate ground waters were associated with soils of high nitrogen content and/or soils receiving high surface loads of nitrogenous material, such as animal manure.

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Oxygen Sag and Stream Self-Purification

Another statistical method for evaluating the self-purification capacity of a stream was presented by Churchill and Buckingham (27). The method of analysis avoids the use of the velocity constants k_1 and k_2 for deoxygenation and reoxygenation. Instead, it involves making a statistical fit of observed data according to the assumed relation:

$$\text{D.O. drop} = a + bL(5) + cT + d/Q$$

where the D.O. drop is the difference, in parts per million, between the dissolved oxygen at a location above the single pollution source and the D.O. level at the critical point of the sag curve; $L(5)$ is the 5-day B.O.D. in parts per million, measured at a location in the vicinity of the critical point; T is the water temperature in °C.; Q is the stream flow in cubic feet per second, and a, b, c, d are constants to be determined by statistical analysis of the data obtained from a set of observed D.O. profiles. Once these constants are derived, they are used to predict critical D.O. levels under reduced pollution load conditions. The significance of the observed relationship is tested by multiple correlation techniques.

The form of this equation is of particular interest in that it assumes a separate simple linear relationship between D.O. drop and each of the variables. While this is not in conformity with the familiar oxygen sag equation, it may be a useful approximation.

In applying the equation to an existing situation, the 5-day B.O.D. was measured at a location quite far downstream from the pollution source (in fact, downstream of the critical point) in order to minimize the variability of this factor and thereby improve the over-all correlation coefficient. The relation between the B.O.D. downstream and the B.O.D. immediately below the pollution source was then derived and tested by statistical analysis. The re-

sulting B.O.D. equation permitted estimates of the B.O.D. reduction at the downstream location due to waste treatment at the source. This information, used in the equation, yielded predictions of the improvement of the critical D.O. level resulting from various degrees of waste treatment. It must be noted, however, that the derived B.O.D. equation predicts a substantial gain in B.O.D. at the downstream point as against an upstream unpolluted location even though 100 per cent B.O.D. removal is assumed at the source by waste treatment.

For satisfactory application of his method of analysis the author estimates that about 18 or 20 sets of data and D.O. profiles will usually be needed. If these data do not result in a sufficiently high correlation coefficient he indicates that more samples will be necessary. It is further indicated that the observed data should include a considerable range in each of the variables, and that D.O. levels should be observed simultaneously at all sampling stations in order to minimize the effects of photosynthesis. A similar discussion based upon the same observed data has been presented by Churchill (28)(29).

A general discussion of some of the factors involved in the self-purification of inland streams and tidal estuaries has been presented by Southgate and Gameson (160). Special attention has been given in this article to the management of rivers, biochemical oxygen demand, rate of atmospheric reaeration, bottom deposits, and effects of synthetic detergents. Reaeration is discussed in terms of the "exit coefficient" f, which is related to the reaeration velocity constant K, by the equation $f = V_K/A$, where V is the volume undergoing reaeration and A is the exposed surface area. These authors have found exit coefficients for shallow turbulent streams to be as much as 200 times as great as the values found for nearly stagnant water. Synthetic detergents had very little effect on the value of f in nearly stagnant or very turbulent water, but resulted in as much as a 50 per cent reduction in f for streams of intermediate turbulence. There is no discussion or note of the effects on f of photosynthesis and respiration of algae.

On the basis of general theory of turbulent flow O'Connor and Dobbins (131) have developed equations for evaluating the rate of atmospheric reaeration in natural streams. It is shown that in turbulent flow, reaeration occurs as the result of molecular diffusion of oxygen through the gas and liquid films at the air-water interface, and thereafter by eddy diffusion (mixing) throughout the main body of liquid. Molecular diffusion through the liquid surface film is the slowest of the processes involved, hence it is the governing process in atmospheric reaeration. As a result, the rate of reaeration is a function of the rate of surface renewal due to turbulence, *i.e.*, the frequency or speed with which liquid surface elements are presented to the atmosphere.

These considerations, together with evaluation of the rate of surface renewal under various flow conditions, have led to the development of theoretical expressions for k_2, the reaeration velocity constant. The relationship between the rates of reaeration and surface renewal was tested experimentally in the laboratory and verified. As further verification, values of k_2 computed by the derived equations have been tested against values reported in the literature from field studies of the Illinois, Clarion, Ohio, and other rivers. The values from field studies of others were selected for river stretches thought to be reasonably free of sludge deposits and algae. There was good agreement between computed and observed results.

Investigations on the Willamette River (147), a stream deficient in ni-

trogen, have led to interesting conclusions regarding the availability of nutrients and rates of biochemical oxidation. It is reported that in nitrogen-deficient streams the rate of oxidation of organic material may be significantly affected by the degree of pollution loading. In such cases, reduction of the pollution load can result in a more favorable B.O.D. to nitrogen ratio and thence to an increased rate of biochemical oxidation.

Several general reviews of factors involved in stream self-purification have been published in foreign journals (13) (104) (105), and Vinberg (176) has reported results of studies on the effects of photosynthesis in polluted waters.

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Stream Studies and Surveys

Investigations and studies of watercourses are receiving due emphasis as result of basin-wide water resource conservation and development programs. Water pollution, as it affects the basic water resource, is becoming increasingly important.

Cramer *et al.* (37) discussed the ramifications of the Missouri River water resource conservation and development program. This comprehensive evaluation included: (a) reservoir building, (b) bank stabilization, (c) flood control, (d) irrigation, (e) navigation, (f) hydro-electric power, (g) improvement in water supply, (h) water treatment problems, (i) sources of pollution and pollution abatement, and (j) chemical analyses of Missouri River water.

Hoak and Bramer (82) presented three methods for estimating the load of suspended solids in streams. The method employed will depend on the quantity and quality of available data, location, accuracy desired, and available time.

Laboratory and field studies were made by Heukelekian and Crosby (79) to evaluate the influence of certain factors on slime formation in treated effluents after various degrees of purification, and in stream waters. It was concluded that the degree of roughness of the submerged surface does not affect ultimate quantity of slime growth; aerobic environment produces more slime than anaerobic conditions; nature and concentration of food affects slime growth; and low velocity during the primary slime formation period increased growths, although higher velocities after the initial period induced greater growths.

Vavasour and Blair (175) studied pulp mill pollution in an arm and a tributary of Notre Dame Bay, Newfoundland, and concluded that the wastes were not present in sufficient quantities to be harmful to fish life. A reconnaissance of chemical and physical quality of Pryor Creek in Oklahoma, reported by Dover and Murphy (46), presented analyses of 69 samples collected at 9 stations over a four-month period; pollution resulted from paper mills and a fertilizer plant. Numerous studies of the effects of water conservation and reservoir construction on rivers and stream pollution have been conducted by interested state and federal agencies.

The effects of pollution on harbor waters received considerable attention. Maxwell (122) conducted a one-year study of hydrobiological conditions in Wellington Harbor, New Zealand, observing temperature, tidal activity, fresh-water run-off, and the effects of pollution consisting of oil and refuse from ships, city sewage, and effluent from a meat freezing company. Pulp mill pollution in Alberni Harbor, British Columbia, was investigated by Waldichuk (178) who concluded that discharge to surface was a good recommendation as advantage is taken of sea-

ward flow and high D.O. content in the surface water. There is the possibility of toxicity, and not just oxygen demand, after plant expansion has been completed.

Larson (102) conducted a factual survey and investigation of sewage and industrial waste disposal in Los Angeles and Los Angeles and Long Beach harbors. Based on this study, the Los Angeles Regional Water Pollution Control Board adopted long range waste disposal and water quality objectives. New York Harbor geography and sampling procedures used by the New York City Department of Public Works are described by Shapiro (151). Romer (145) discussed the health department's interest in bathing and shellfish growing waters of New York City Harbors. It was found that coliform densities increased dramatically after heavy rains, making it necessary to evaluate the safety of Jamaica Bay waters for bathing after summer rainfalls that might occur twice a week. Average daily coliform densities cannot be used, as short-time (6 hr.) densities may be excessively high.

Ingram (89) studied methods of treating cabin cruiser toilet wastes and concluded that grinding and chlorination reduced coliform densities and produced wastes that could be discharged without serious health hazard or nuisance.

Valuable water quality data have been collected by the United States Geological Survey. Love (114) reported on over 100 river stations in 10 southwestern states in the Lower Mississippi River and Western Gulf of Mexico basins. Chemical analyses included silica, iron, calcium, magnesium, sodium, HCO_3, potassium, chlorine, SO_4, and NO_3, and, in most instances, fluorine, boron, suspended sediment, temperature, pH, specific conductance, and color. A report of the quality of surface waters for irrigation in western United States by Love (115) presented a chemical analysis, chiefly salt burden, and other physical measurements for a network of stations west of the Mississippi River. Lamar, Krieger and Collier (100) reported the chemical quality, suspended sediment and water temperatures of surface waters of Kentucky.

The relationship of the chemistry of Minnesota surface waters and wildlife management was discussed by Moyle (128); the report gives ranges of pertinent chemical constituents: total alkalinity, SO_4, chlorine, phosphorus, and total nitrogen. Two reports of chemical composition of Texas surface waters were issued by the Texas Board of Water Engineers (4)(5).

Abatement and Control

The spotlight on water pollution control legislation centered on the passage of the Federal Water Pollution Control Act of 1956 by the 84th Congress (139). This act is administered by the Surgeon General of the Public Health Service. The act, as finally passed by Congress, reaffirms the policy of Congress to recognize, preserve, and protect the primary responsibilities and rights of the states in preventing and controlling water pollution. The act authorizes grants to state and interstate agencies, up to $3 million per year for five years for pollution control activities, and $50 million per year for the construction of municipal sewage treatment works. It further authorizes increased technical assistance to states, a broadened research program, and the collection and dissemination of data on water quality relating to control of water pollution. The enforcement measures against the pollution of interstate waters, as originally provided for in P.L. 845, were modified, and federal installations were authorized to cooperate with state and interstate agencies or municipalities in preventing or controlling pollution from these sources.

Hollis and McCallum (83) have expressed the USPHS philosophy as that

of supplying those services needed to complement the work of state and interstate agencies, communities, and industries in order to attain a well balanced national pollution control program. They point out the need for better public understanding to insure that the proper proportion of the municipal tax dollar will go toward the abatement of pollution. They estimate that, to make up the backlog of needed municipal works over the next 10 years, and to take care of population growth and treatment plant obsolescence, it will require doubling the average per capita expenditure now going into municipal construction, or about $500 million annually.

Weston (184) indicated that industry in the United States has spent at least $1 billion for water pollution abatement facilities, and estimated that from $4 to $5 billion additional will be necessary to control industrial pollution during the next 10 years.

Hess (76), Watson (183), and Weston (185) all discussed the activities of industry in the field of industrial pollution control research. The need for development of improved analytical methods for analyzing industrial wastes, as well as research on methods for waste control, is emphasized. The authors pointed out that better information is required on quality indices and pollutional effects of specific wastes on receiving waters.

Municipalities are devoting increasing attention to the development of factors involved in the preparation and administration of municipal ordinances relating to the discharge of industrial wastes into municipal sewer systems. Reich (141) pointed out that at Philadelphia, Pa., pretreatment requirements for industrial wastes are based on whether they will upset the operation of the plant, will damage sewerage structures, affect the hydraulic characteristics of the sewers, or will be harmful to maintenance and operating personnel. He emphasized the need for good public relations with industry and the importance of working cooperatively with industry on their problems.

Taylor (168), speaking for Cincinnati, discussed industrial waste ordinances and the experience with adoption and enforcement of such ordinances in that city. The Cincinnati ordinance, as amended in 1953, provides for a maximum of flexibility with provision for separate rules and regulations controlling discharge to public sewers. The Cincinnati ordinance provides for a sewer service charge, with a surcharge on industrial wastes which impose an unreasonable burden on the sewage disposal system. It also prohibits any wastes which will damage the system or which cannot be treated satisfactorily.

Shaw (152) discussed the pros and cons of sewerage authorities, particularly from the standpoint of experiences in New Jersey. Advantages cited are: more rapid action, decreased financial liability to local governments, and relief of administrative burden on elected officials. The disadvantages indicated are: undue delegation of authority to a relatively independent agency and increased cost of financing as compared with municipal financing.

On the foreign scene it is noted that the Scottish Rivers Purification Committee (170) was being formed. The purpose of this committee is to advise on the cleanliness of waters, including tidal waters, to prevent the pollution of these waters, and to consider and make recommendations concerning the abatement and control of pollution. Southgate and Gameson (160) reviewed recent developments in the control of pollution in England, starting with 1927 when the Water Pollution Research Board was established. He mentions the two kinds of standards used in the control and prevention of pollution ("effluent" and "stream") and cites reasons why the latter is preferred. He also points out that their

studies indicate that the capacity of an estuary to purify sewage and trade wastes is much more limited than is often supposed.

Stream Standards

Garber (61) examined the status of bacterial standards for natural bathing waters. He found a wide variation in standards used, from essentially no coliforms to a median of $< 2{,}400$ M.P.N. per 100 ml. Authorities cited satisfactory epidemiological experience with standards throughout this range. Of numerous methods for measuring average or index values he selected the geometric mean as most applicable. The inadequacies of bacterial groups used as indicators of pathogenic contamination and the difficulties of reliable interpretation of the results obtained point up the need for improved methods. He concluded that unjustifiably stringent standards can lead to unnecessarily costly sewage treatment.

The California State Water Pollution Control Board (6) set numerical values to govern sewage discharge from the Los Angeles Hyperion plant. The order establishes three areas in Santa Monica Bay. All must be free of recognizable floating or suspended sewage solids. The outfall area, for dilution and dispersion, must have at least 6 p.p.m. of dissolved oxygen, and grease shall not exceed 2 p.p.m. in 3, or 20 per cent in 20, consecutive samples. Coliform organisms in the beach area shall not exceed 10 per ml. in more than 20 per cent of the samples. In the intermediate area coliforms shall not exceed 100 per ml. and transparency, by the Secchi Disk, shall be at least 20 ft. 50 per cent, and 15 ft. 80 per cent, of the time.

Lester (108) reviewed development of English control legislation from the 12th century to the "River Boards and the Rivers (Prevention of Pollution) Act, 1951." This Act empowers the 32 river boards to adopt bylaw standards. It is assumed that bylaw standards would apply only to existing sources of pollution. Consent of the boards, which may include individual standards, is required for discharge of new wastes. The trend is toward the Royal Commission on Sewage Disposal recommendation that a sewage effluent shall not contain more than 20 p.p.m. 5-day B.O.D., nor 30 p.p.m. suspended solids, and shall not exceed a specified volume. Industrial effluents should meet these requirements and also should be non-toxic to fish or fish spawning grounds, spawn, or food for fish. The standards should not be exceeded in a single sample.

Hart (71) presented the case for stream standards as opposed to effluent standards. He recognizes, however, possible usefulness of effluent standards when a waste constitutes the entire flow of a stream, or when it becomes necessary to pinpoint responsibility of a recalcitrant polluter.

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Sewage Works

BIOCHEMICAL OXIDATION OF VARIOUS PARTICULATE FRACTIONS OF SEWAGE *

By J. L. Balmat †

Rutgers University, New Brunswick, N. J.

It has been well established that the biochemical oxidation of the organic matter in domestic sewage can be defined loosely as a monomolecular reaction—

$$\text{Log} \cdot \frac{L_t}{L} = -k_1 t$$

where

L = the ultimate B.O.D.;
L_t = the B.O.D. at time t; and
k_1 = the rate constant.

This means that the rate of biochemical oxidation is proportional only to the concentration of the remaining unoxidized material. Thus, it may be assumed that either (a) all of the organic constituents comprising this complex waste oxidize at the same rate regardless of chemical composition or particle size, or (b) the multitude of biochemical processes occurring simultaneously and sequentially have different rate constants which, collectively, give the impression that the over-all process progresses in a manner similar to that of a monomolecular reaction.

A review of the literature disclosed only one paper containing evidence in support of either assumption. A measurement of the B.O.D. of the course, finely divided, and soluble solids of fresh sewage by Rudolfs and Gehm (1) revealed that each fraction had a different B.O.D.-volatile matter ratio. Furthermore, the rate of biochemical oxidation of the soluble material was less than that of the finely divided material.

The lack of information on the subject resulted in the decision to measure the B.O.D. rate constant (k_1) of the settleable, supracolloidal, colloidal, and soluble solids present in fresh domestic sewage. In this way it might be possible to estimate the influence of particle size on the rate of biochemical oxidation. In addition, the results would have significance in terms of the current sewage treatment practices of sedimentation and chemical coagulation.

Experimental Methods

Fractionation of Sewage Solids

The detailed procedure for the fractionation of sewage solids has been given in previous publications (2) (3); accordingly, only a brief summary will be given here. The settleable solids were removed according to the procedure described in "Standard Methods" (4) which allows the fresh domestic sewage to stand under quiescent conditions in an Imhoff cone for 1 hr. The settleable solids were greater than 100μ (micron) in size. At the end of the settling period the supernatant was

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siphoned off and fractionated further. Continuous centrifugation in a Sharples supercentrifuge under controlled conditions removed the "supracolloidal" sewage solids of 1 to 100μ in size. The effluent from the supercentrifuge was filtered under high pressure through an ultrafilter membrane to remove the colloidal solids of 0.08 to 1μ in size. Only the dissolved solids remained in the filtrate.

B.O.D.

The B.O.D. rates and volatile solids determinations were made on the solids of the four sewage fractions and combinations of fractions. The rate studies on the sewage solids, suspended in B.O.D. mineral dilution water containing 1 per cent sewage seed, were made over a period of five days at 20° C. using the Warburg technique (5). The Moore method (6) was used to calculate the rate constant (k_1).

Results

During a period of several months, four different rate studies were made on raw sewage and its fractions. Samples having different strengths had different proportions of the four sewage fractions and therefore contributed different amounts to the total strength of the sewage.

TABLE I.—B.O.D., Rate Constant (k_1), and Volatile Solids of Raw Sewage and its Fractions

Sewage Sample	Determination		
	k_1*	B.O.D. (p.p.m.)	B.O.D. † / Vol. Sol.
Raw	0.22	315	0.85
Settleable	0.08	48	0.95
Nonsettleable	—	269	0.85
Supracolloidal	0.09	89	0.97
Colloidal-soluble	—	117	0.84
Colloidal	0.22	49	1.26
Soluble	0.39	127	0.75

* Rate of biochemical oxidation.
† Ratio of B.O.D. to volatile solids.

The ratio of B.O.D. to volatile solids, and the B.O.D. rate constants (k_1) for the raw sewage and the sewage fractions remained constant within 5 to 10 per cent. Therefore, one of the sets of data that represents about the average results is given in Table I.

Discussion

B.O.D.

The B.O.D. curves in Figure 1 are of two types: (a) those in which the soluble fraction was present, and (b) those in which the sewage solids were suspended in seeded mineral dilution water. The first type includes the raw sewage; nonsettleable sewage, containing the soluble, colloidal, and supracolloidal solids; and the colloidal-soluble solids.

The B.O.D. curves of the first type (Figure 1, Curves 1, 2, 3, 4) represent a "normal" rate of biochemical oxidation and constitute a monomolecular type of reaction. The B.O.D. curves of the second type (Figure 1, Curves 5, 6, 7) show a somewhat linear relationship of B.O.D. to time. The rate-controlling factor of the insoluble sewage solids decomposition appears to be the rate of hydrolysis prior to biochemical oxidation. Because bacteria can only utilize soluble food as a source of energy, the rate at which food is utilized can be no greater than the rate at which it is made available.

In the B.O.D. rate studies of the soluble fraction of sewage solids, a lag was experienced for the first 12 hr., during which the sample exerted no oxygen demand. After this lag period the rate of oxidation proceeded as shown in Figure 1. Because such a lag did not occur when the soluble solids were present with other sewage fractions, it was considered to be an artifact. The time of the lag was subtracted from the data so that initiation of biochemical decomposition began at time zero. The lag was probably due to insufficient seeding of the soluble fraction. A 1 per cent concen-

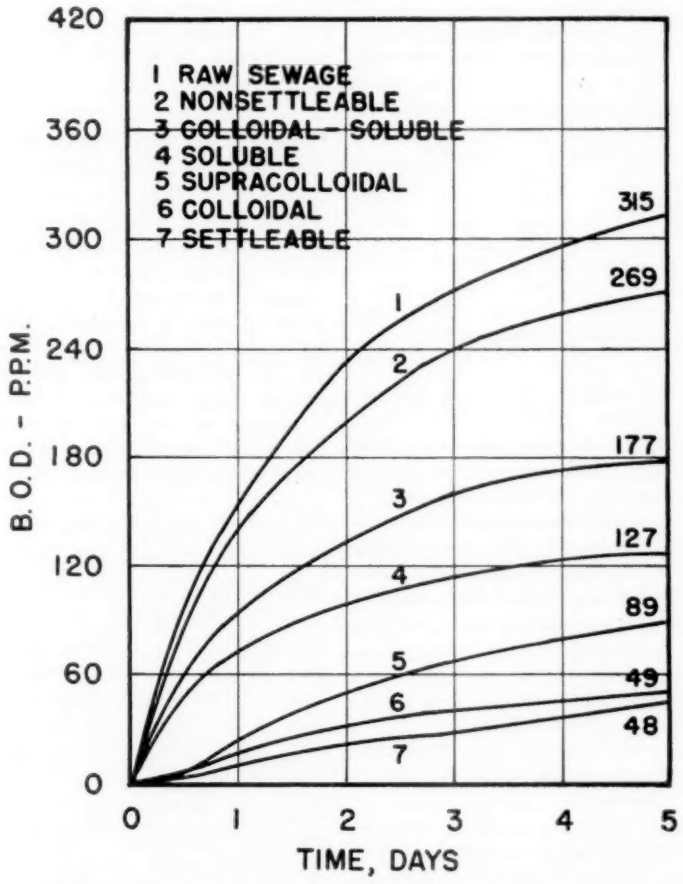

FIGURE 1.—B.O.D. curves for the particulate fractions of sewage.

tration of seed was used, but this may not have been enough.

The break in the B.O.D. curves for the settleable, supracolloidal, and colloidal solids at the two-day point may indicate that there are two general types of substances with different degrees of susceptibility to biochemical oxidation.

The data given in Table I show that the B.O.D. rate constant (k_1) increases with decreasing particle size. This clearly demonstrates why the B.O.D. curve of raw sewage for the first 1½-day period is dominated by the dissolved solids rather than the nonsettleable solids.

The differences in the data on the B.O.D.-volatile solids ratio for the various fractions and combinations can be explained, in part, on the basis of the soluble bicarbonates present in all samples containing the soluble fraction. The bicarbonates upon ignition (in the determination of volatile solids) are measured as part of the volatile solids but they do not have a B.O.D.

Thus, those samples containing the soluble fraction (raw sewage, nonsettleable solids, colloidal-soluble solids,

TABLE II.—Raw Sewage as the Sum of its Fractions

Sewage Sample	Determination		
	k_1*	B.O.D. (p.p.m.)	×
Settleable	0.08	48	3.8
Supracolloidal	0.09	89	8.0
Colloidal	0.22	49	11.0
Soluble	0.39	127	50.0
Total of fractions	—	313	72.8
Raw	0.22	315	69.0

* Rate of biochemical oxidation.

and soluble solids) will have a lower value for the B.O.D.-volatile solids ratio. In the soluble fraction alone where the bicarbonates constitute a greater proportion of the volatile solids, the B.O.D.-volatile solids ratio should be the lowest. The facts appear to follow the logic of the explanation.

The B.O.D. rate of the raw sewage is the sum of the weighted k_1 values for all the fractions. This is shown in Table II, where

$$k_1 \times \text{B.O.D. (raw sewage)} = \Sigma k_1 \times \text{B.O.D. (fractions)}$$

within 5 per cent. Table II also shows that:

$$\text{B.O.D. (raw sewage)} = \Sigma \text{ B.O.D. (fractions)}.$$

By substituting values of k_1 for each sewage fraction (Table II) in the B.O.D. equation

$$\frac{L_t}{L} = 10^{-k_1 t}$$

the per cent of the remaining organic matter oxidized on each successive day can be calculated. These values are:

Fraction	Per Cent
Settleable	16.7
Supracolloidal	18.6
Colloidal	39.6
Soluble	59.2

These values reveal that, during the first five days of biochemical oxidation, the rate at which the soluble organic matter in raw sewage is being oxidized is 320 per cent higher than that of the supracolloidal solids and 150 per cent higher than that of the colloidal solids. This appears to contradict the results of the oxidation rate studies conducted by Rudolfs and Gehm (1) who concluded that the rate of biochemical oxidation of the soluble material is markedly less than that of the finely divided material.

Conclusion

The rate at which the settleable and supracolloidal sewage solids, relatively large in particle size, undergo decomposition may be limited by the slow rate of biochemical hydrolysis ($k_1 = 0.08$). The soluble organic matter, that which requires no physical diminution prior to ingestion and utilization by the bacteria, has a k_1 value (0.39) that may represent the rate of biochemical oxidation. This indicates that comminution of some wastes to a particle size of 1μ or less may greatly increase their rate of biochemical decomposition, thereby permitting a higher loading at the waste treatment plant.

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Admission is open to persons with bachelor degrees in some branch of engineering and who meet the entrance requirements of the school. Details may be obtained from the Department of Civil Engineering, Illinois Institute of Technology, Chicago 16, Ill.

University of Cincinnati

The University of Cincinnati has announced a new graduate program in sanitary engineering. Graduate students will have the opportunity of working with the Institute of Industrial Health, Kettering Laboratory, Robert A. Taft Sanitary Engineering Center, Ohio River Valley Water Sanitation Commission, Tanners Council Research Laboratory, and the City of Cincinnati Division of Sewage Disposal. Engineers and scientists from these cooperating organizations will assist the University's Civil Engineering Department in formulating and staffing courses.

The program is open on a full- or part-time basis and leads to the Master of Science degree in sanitary engineering. Information can be obtained from the Department of Civil Engineering, University of Cincinnati, Cincinnati 12, Ohio.

SOLVING THE SEWERAGE PROBLEM AT UKIAH, CALIFORNIA *

By Roger F. Wilcox and Douglas S. Cruickshank

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The Problem

There are many factors present in the economic environment of Ukiah, Calif., which have increased the population and created fringe areas. Ukiah, the county seat of Mendocino County, is the retail trade center of what is primarily an agricultural and lumbering area. The construction of manufacturing facilities for the Masonite Corporation immediately north of Ukiah was a major industrial development which brought many people to the area in the late 1940's. In addition to this industry and the agriculture, recreational facilities in Mendocino County are exceptional, and Ukiah is a favorite tourist stopping point on the Redwood Highway.

Since 1940 the population of Ukiah has increased from 3,500 to a present estimate of more than 10,000 persons. Fringe areas have experienced similar increases. There is a national trend toward suburban living as shown by the fact that while the total population has been increasing rapidly during the past few years, the population of fringe areas, or suburbs, has been increasing at a much more rapid rate. It is expected that Ukiah will be no exception to this trend, and a sewerage program capable of serving a large portion of the Ukiah Valley must be planned.

Historical Background

The first sanitary sewerage system in Ukiah was constructed prior to 1900, and consisted of collection sewers and a septic tank near the Russian River. Most of the original sewers are still in use, some having been in service more than 75 years. These old sewers have been found to have open joints and some show porous deterioration. The original septic tank became incapable of treating increased flow and was replaced by an Imhoff tank in 1919. The latter in turn was replaced in 1940 by a primary treatment plant with separate sludge digestion. The rapid growth of the city during and following World War II made it necessary in 1949 to enlarge the treatment works and install a chlorinator.

Within a few years it became evident that the 1949 enlargements were not sufficient to handle increasing sewage flows, especially during wet weather. Ground water infiltration into the sewers during the rainy season caused flooding of pretreatment units at the plant and surcharging of the sewers. Raw sewage overflowed into city streets and a health hazard existed.

The sanitary sewerage system of Ukiah provides service for almost all the area within the city limit, but no provision was made to extend service to outside areas. There are now several well-developed fringe areas, especially south of town, which need sanitary sewers but cannot be served by this system. The usual pattern of septic tanks in early stages, with scattered houses, has not been too successful because of soil conditions and a high water table. With accelerated population growth and the trend toward sub-

* Presented at the 1956 Annual Meeting, California Sewage and Industrial Wastes Assn.; Santa Rosa, Calif.; April 25–28, 1956.

division home building, septic tanks have become completely unsatisfactory. Because of this, local health authorities have refused to issue permits for new construction on lands previously subdivided. A small activated sludge treatment plant was installed in one large subdivision in an effort to solve the sewage problem. This type of solution is expensive and frequently unsatisfactory.

Tremendous economic pressure developed as a result of a rapidly expanding population that could reside only in fringe areas for which adequate sewerage facilities must be provided. This fact, plus the experience with city treatment facilities that have become obsolete four times in less than 40 years, points up the need for careful advance planning.

Programs and Engineering Studies

City of Ukiah

In 1953 the City Council of Ukiah retained a consulting engineering firm to make an engineering study of all phases of the sewerage problem and to prepare a report setting forth the nature and the estimated cost of needed improvements.

A complete study was made of existing sewer and drainage facilities, including data on flow, infiltration, and sewage characteristics. After careful analysis of first and operational costs, a long-range plan for stepwise construction of improvements was proposed. Population densities were estimated for the year 2000, at which time the total population for the Ukiah area is expected to reach 30,000.

Measurements made during wet weather showed in many instances that more than 75 per cent of the sewage flow was due to storm water infiltration and that the infiltration rate in certain areas exceeded 6,000 g.p.a.d. Leakage in these areas was quite general and nothing short of actual replacement of the sewers would do much to reduce it. Since replacement would be economically impossible, trunk sewers were designed with sufficient capacity to carry, in addition to sanitary sewage, all storm water gaining access to the existing system.

At the time of the engineering study, the City of Ukiah was discharging sewage into the Russian River under a permit issued in 1948 by the Bureau of Sanitary Engineering, California State Department of Public Health. It was expected that the Regional Water Pollutional Control Board requirements, when set, would be patterned after the original requirements, and that only a "well-oxidized, stable, and adequately disinfected effluent" could be discharged. Such an effluent could be obtained only by complete treatment in a trickling filter or activated sludge plant, supplemented either by effluent chlorination or by effluent detention in stabilization ponds. Studies showed a trickling filter plant with effluent chlorination to be most desirable.

Studies of the fringe area showed a choice between two possible sewerage projects, each of which involved a separate and entirely different trunk sewer system and treatment plant location (Figures 1 and 2). These projects were:

Plan A.—Continued use of the existing treatment plant site with reconstruction and enlargement of its facilities.

Plan B.—Abandonment of the existing plant and construction of a completely new plant at a suitable location south of the town.

Both plans called for the improvements to be made in three stages, each based on a program of stepwise construction designed to meet both present and future needs. Included in the first stage were those sewers which would be required immediately to eliminate existing deficiencies. The second stage included trunk sewers and new treatment facilities to be constructed as

FIGURE 1.—Proposed sewerage improvements, Ukiah, Calif., under Plan A.

soon as the necessary funds became available. The third stage included trunk sewers required to serve areas expected to become tributary in 15 to 20 years.

There was not much difference between the costs of the two plans. The total ultimate cost of Plan A was $925,500, while Plan B was estimated to cost $934,000. Plan A was recommended

by the engineering firm, mainly because of the lower first cost. The fact that the City of Ukiah possessed usable trunk sewers which would fit into Plan A and also owned 23 acres at the existing plant site influenced the decision.

County Sanitation District

On August 1, 1953, the Board of Supervisors of Mendocino County authorized a consulting engineering firm to proceed with a survey and engineering analysis of sewerage and related sanitation problems throughout the county. The Board instructed the engineers to take all steps necessary to accomplish the following objectives:

1. Examine the existing sewerage, drainage, water supply, and waste disposal conditions in all of the drainage areas of the county.
2. Provide the residents in each of the communities with an engineering analysis of their problems, including information necessary for proper planning and action between communities themselves.

In December, 1953, an interim report was issued covering the Ukiah Valley area. The report indicated that the area from the Orrs Springs Road on the north to Robinson Creek on the south, including the City of Ukiah, could be economically sewered through a trunk sewer and a treatment plant located just to the south of Norgard Lane. County and city officials held preliminary discussions immediately after the review of this report by both bodies.

On July 6, 1954, the Board of Supervisors of Mendocino County created the Ukiah Valley Sanitation District for the purpose of providing urgently needed sewerage facilities for the rapidly growing unincorporated areas suburban to the City of Ukiah. The boundaries of the district, as finally organized, extended from the Masonite Road on the north to Robinson Creek on the south and from the flood plain of the

FIGURE 2.—Plan B, alternative plant site and outfall sewer.

Russian River on the east to the hills which border the western side of the valley. The City of Ukiah, however, which lies within this area, was excluded from the district, in order that the city might continue to analyze its position with respect to relative benefits from:

1. Inclusion of the city within the sanitation district.
2. A joint sewage disposal project under contract with the district.
3. Separate sewerage facilities.

In August, 1954 the Ukiah Valley Sanitation District received from the consulting engineering firm a report which made recommendation of two basic plans for serving the sanitation district.

The first plan proposed a trunk sewer, a treatment plant, and a provision for by-passing peak winter flows to the existing treatment plant. Financing was proposed either through the inclusion of the City of Ukiah in the sanitation district or by a contract-

ual agreement between the sanitation district and the city for the use of the joint facilities. The second plan proposed separate sewerage facilities for the sanitation district with no provision for the inclusion of the city.

Cooperative Planning

Topographic features of the valley and factors of economy through the joint use of trunk lines and treatment facilities, made it clear that the only practical means for providing adequate sanitary sewage facilities for the city and the Ukiah Valley area included in the sanitation district would be through a joint facility. The only problem which remained to be solved was on what basis each of the political entities should participate in the improvement. After several joint meetings, a definite basis for action was agreed on as follows:

1. Joint action was desirable.
2. By-pass of the peak winter flows through the existing City of Ukiah facilities was not desirable.
3. A division of actual costs for the project should be based on the ratio of use to each of the political entities involved.

In the spring of 1955, the following plan of action was agreed upon:

1. The City of Ukiah would construct a sewage treatment plant south of the city of sufficient size to serve both the fringe areas included in the district and the City of Ukiah. The cost was not to exceed $600,000 (approximate cost required for improvement of the collection and treatment facilities within the city).
2. The Ukiah Valley Sanitation District would construct a trunk line to the treatment plant which would provide collection facilities for the city and the related fringe areas of the district for a period of 40 years.
3. If the cost of either of the facilities proposed should exceed the estimates given, the City of Ukiah would pay two-thirds of the excess and the Ukiah Valley Sanitation District would pay one-third.
4. The City of Ukiah would operate the treatment plant and maintain the trunk lines. The annual cost of operation and maintenance is to be divided between the city and the district on the basis of the number of connections.
5. Policies involving both the district and the city would be settled at joint meetings of the two boards.

In September, 1955 the citizens of both areas approved the bond issues by an overwhelming majority. The City of Ukiah was authorized to issue $846,000 worth of revenue bonds secured by the receipts of a sewer service charge. The Ukiah Valley Sanitation District was authorized to issue $485,000 worth of general obligation bonds.

Solution of the Problem

In May, 1954 the Regional Water Pollution Control Board set requirements for final disposal of effluent from the City of Ukiah's sewage treatment plant in Ukiah Valley. Some of the requirements were more stringent than originally expected. The principal item was the requirement that in effect meant that no effluent could be discharged directly into the Russian River during the summer recreational season —May 1 to September 30 inclusive. This involved changes in the sewage treatment plan that were estimated to impose an additional cost of about $35,000, mainly for land required for detention ponds and emergency standby power.

The treatment plant will be designed as a modified trickling filter plant, utilizing stabilization ponds for the final step in secondary treatment. These ponds will have ample volume to satisfy the detention requirements. Primary and secondary sedimentation tanks and the sludge digesters will be

designed as dual units, while only one large trickling filter will be utilized.

The trunk sewer system will be designed to collect the sewage of the entire Ukiah area by gravity, essentially as laid out in the engineering studies previously mentioned. A lift station at the treatment plant will pump the sewage into the primary tanks.

The City of Ukiah will provide for the preparation of plans and specifications for both the treatment plant and the trunk line. A 60-acre site has been purchased for location of the treatment plant and ponds. It is expected that the costs for the facilities will be slightly in excess of the value set by either of the consultants in their preliminary reports, due to the need of the additional land for the stabilization ponds.

Within two years the treatment facilities and the trunk lines will be in operation and the collection districts will have completed the installation of street mains in the fringe areas. With the completion of this project it is expected that the Ukiah Valley will be ready to capitalize on the decentralization of industry.

MEETINGS OF INTEREST

1957

Aug. 19–23 **Massachusetts Institute of Technology.** Disposal of Industrial Wastes from the Textile Industry. Summer Session, M.I.T., Cambridge 39, Mass.

Aug. 20–22 **Northwestern University.** Liquid Scintillation Counting. Associate Professor Carlos G. Bell, Jr., Northwestern University, Evanston, Ill.

Aug. 26–28 **Hydraulics Division,** American Society of Civil Engineers, Kresge Auditorium, Massachusetts Institute of Technology, Cambridge, Mass.

Sep. 15–18 **American Institute of Chemical Engineers,** Lord Baltimore Hotel, Baltimore, Md., F. J. Van Antwerpen, Secretary, 25 West 45th St., New York, N. Y.

Sep. 22–25 **Public Works Congress and Equipment Show,** Philadelphia, Pa. Donald F. Herrick, Executive Director, American Public Works Association, 1313 East 60th St., Chicago 37, Ill.

Oct. 7–10 **Federation of Sewage and Industrial Wastes Associations,** Hotel Statler, Boston, Mass.

Oct. 7–8 **Bavarian Biological Institute,** Munich, Germany. Advance course in the biological and chemical problems of trickling filters and activated sludge. Dr. H. Liebman, Bayerische Biologische Versuchsanstalt, Veterinarstrasse 13, Munich 22, Germany. Applications by Sep. 30.

Oct. 14–18 **American Society of Civil Engineers,** Annual Convention, Hotel Statler, New York, N. Y. W. H. Wisely, Executive Secretary, 33 West 39th St., New York 18, N. Y.

AERATION REQUIREMENTS OF A HIGH OXYGEN DEMAND SEWAGE*

By Robert D. Bargman, Jack M. Betz, and William F. Garber

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The Hyperion Treatment Plant of the City of Los Angeles (Calif.) provides for an intermediate-grade secondary treatment of the raw sewage. Raw influent is given approximately 0.5 hr. of preaeration, 1.5 hr. of primary settling, 3 hr. of high-rate aeration, and 2 hr. of secondary settling. The effluent is given sub-residual chlorination, and is discharged at sea through a submarine outfall 5,000 ft. long. The high-rate aeration design was based on work performed by the City of New York and previously reported (1)(2)(3).

The aeration system at Hyperion was placed in operation in March, 1951. Since that date it has been an effective portion of the treatment process, contributing in a large part to the removal of 75 to 85 per cent of the B.O.D. and suspended solids, and to the maintenance of chlorine-demand levels amenable to economic polishing chlorination. The conditions and mechanics of operation of the aeration process, however, have been different from those predicted during the design period. Additional air supply and certain equipment, added to enable flexibility in process manipulations, have made the operation satisfactory although somewhat difficult to control.

The material in this paper is derived primarily from experimental work aimed at obtaining positive control of the aeration process at Hyperion and increasing aerator efficiency. It was apparent early that aeration at Hyperion did not fit the so-called typical patterns outlined in texts and in data from other plants. The economic consequences of poor aerator operation, manifested in high chlorine demand, high chlorination rates, and spiralling treatment costs, made understanding of the differences imperative. The investigations that have led to adequate secondary treatment control are discussed in this paper.

Operational Results

Primary sedimentation tanks are utilized ahead of aeration and it might be presumed that difficulties arising in these units would introduce variables of considerable dimensions into any study of the following processes. Current loading rates on the primaries have impaired their efficiency and the high-rate aeration process has had to assimilate loadings beyond those originally anticipated. A comparison between design objectives and operating results is given in Table I. Although the original loadings on the aeration units are in excess of the design load, the removals meet or exceed design expectations.

Suspended Solids and B.O.D.

One of the peculiarities of the high-rate aeration system is the variance of the suspended solids and B.O.D. content of the secondary effluent. Table II shows the results obtained from May through December, 1956. These data represent results obtained

* Presented at the 29th Annual Meeting, Federation of Sewage and Industrial Wastes Assns.; Los Angeles, Calif.; Oct. 8–11, 1956.

since construction changes minimizing return sludge degradation were completed. Very close process control has been emphasized. It will be noted, however, that the secondary effluent during this period varied from a maximum of 96 p.p.m. suspended solids and 58 p.p.m. B.O.D. to a minimum of 58 p.p.m. suspended solids and 46 p.p.m. B.O.D. During the same period, the average of the maximum day in each of the eight months was 100 p.p.m. for suspended solids and 76 p.p.m. for B.O.D.; the corresponding minimums were 43 p.p.m. and 34 p.p.m., respectively.

The individual daily suspended solids and B.O.D. content of the secondary effluent obtained over a 24-month period have been subjected to a statistical analysis and found to be a valid series of observations; that is, the deviations from the mean follow a straight line probability pattern. The standard deviation is high but nonetheless significant. The fact that there is a valid but large standard deviation from the mean in the secondary effluent must rest therefore with a fundamental instability in the high-rate aeration process itself. This is not surprising since the high-rate process operates in the logarithmic growth period of activated sludge and only small quantities of sludge are available for buffering and "smoothing out" action.

TABLE I.—Comparison of Treatment Results

Item	Design Basis	Operating Results*
Sewage flow (m.g.d.)	245	254
Raw sewage:		
Susp. solids (p.p.m.)	340	338
B.O.D. (p.p.m.)	250	241
Primary treatment:		
Susp. solids removal (%)	57	31.5
B.O.D. removal (%)	—	19
Effl. susp. solids (p.p.m.)	146	231
Effl. B.O.D. (p.p.m.)	—	195
Secondary treatment:		
Susp. solids removal (%)	65	68.5
B.O.D. removal (%)	—	73.5
Effl. susp. solids (p.p.m.)	51	73
Effl. B.O.D. (p.p.m.)	69	52
Over-all treatment:		
Susp. solids removal (%)	85	78.5
B.O.D. removal (%)	72.5	78.5

* May through December, 1956.

TABLE II.—Secondary Effluent Characteristics of the High-Rate Aeration Process

Monthly Average (1956)	Secondary Effluent	
	Susp. Solids (p.p.m.)	B.O.D. (p.p.m.)
May	70	50
Jun.	63	46
Jul.	58	46
Aug.	71	55
Sep.	64	57
Oct.	69	55
Nov.	96	58
Dec.	91	50
Over-all	73	52

If the suspended solids content of the raw sewage over any given period is plotted against the suspended solids content of the secondary effluent, a "scattergun" chart is obtained. It thus appears that no interrelation exists between the solids content of the raw influent and that of the secondary effluent within the values experienced to date.

Within the limits experienced to date, the terminal results of the high-rate aeration technique as practiced at Hyperion appear to be independent of the solids and B.O.D. loading. The approximate limits of loading experienced during the period of May through December, 1956, are shown in Table III. If this observation also holds for changes in loading greater than those indicated in Table III, this factor would be of considerable significance in design practices.

Chlorination

The reduction of the chlorine demand is significant wherever disinfection of plant effluent must be practiced.

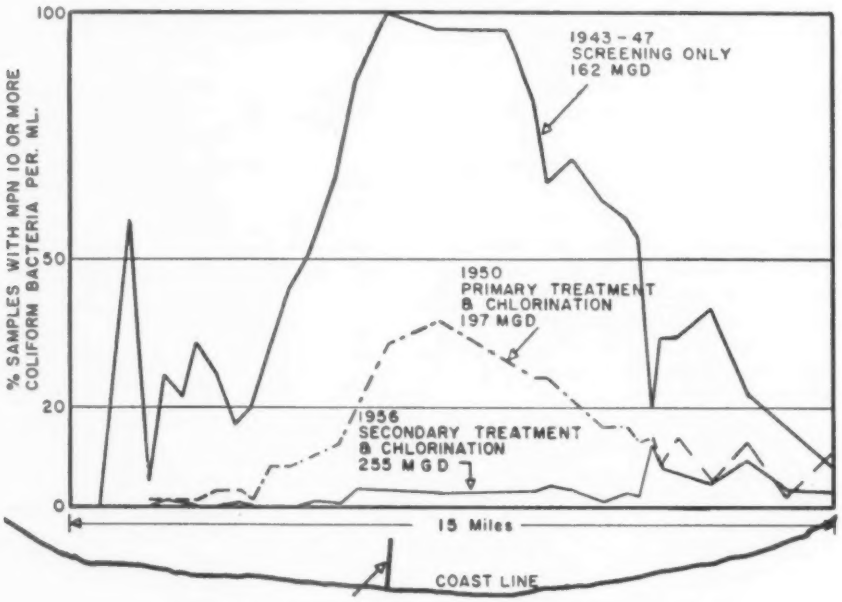

FIGURE 1.—Bacterial indices, Santa Monica Bay, Calif.

Figure 1 shows the bacterial indices found on the beach immediately adjacent to the treatment plant in 1950 when primary sedimentation alone was used. The flow was 197 m.g.d., and the use of 13.0 tons of chlorine per day gave only partial control compared to the present 7.85 tons per day used on a flow of 255 m.g.d. of secondary effluent which gives satisfactory beach counts. Also shown is the curve of bacterial indices obtained in 1943–47 on a flow of 162 m.g.d. which received only fine screening.

Determination of the chlorination rate has been by a variation of the former standard immediate-demand method of the American Public Health Association, which was called the Hyperion guide method. This was a quick method by which operating personnel could run hourly demands and adjust chlorination accordingly. Recently, the efficacy of the Hyperion guide method and the former 15-min. demand method has been tested by controlling chlorination according to the indicated demand and then obtaining coliform index counts over a 24-hr. period directly in the chlorinated plant discharge. The actual test is made on the sewage-sea water mixture above the terminus of the submarine outfall.

These tests indicated that the orthotolidine chlorine demand did not adequately represent the degree of chlorination necessary. The maximum rates were not high enough and the minimums were not low enough. As a result, chlorination is on a program schedule based on the coliform index surveys of the plant discharge. The secondary effluent is chlorinated to only 25 to 50 per cent of the 15-min. chlorine demand; accordingly, instruments such as the amperometric titrator cannot be used.

Under present treatment conditions the 15-min. chlorine demand of the secondary effluent averages 12 p.p.m.

TABLE III.—Monthly Average of Loading on Secondary Treatment System

Item	Loading	
	Maximum	Minimum
B.O.D. (lb./day)	475,000	336,500
Susp. sol. (lb./day)	568,000	410,500

Under optimum conditions the 15-min. chlorine demand of the primary sedimentation tank effluent has averaged 29 p.p.m. In the case of primary sedimentation tank effluent, as with the control of the rate of chlorination, reliance on chlorinating to the demand can result in erroneous procedures. The primary effluent contains particles that are not easily penetrated by chlorine; therefore, chlorination to the 15-min. demand does not always result in an adequate bacterial kill. Bacterial indices are given in Table IV for results found in laboratory experiments where secondary and primary effluent were treated to various percentages of the 15-min. chlorine demand and held for a period equivalent to the flow time through the existing outfall.

TABLE IV.—Changes in *Coli aerogenes* Index Noted Under Different Rates of Chlorination *

Per Cent Chlorination	*Coli aerogenes* per Milliliter (Geometric Mean of M.P.N.)	
	Primary Sedimentation†	Secondary Sedimentation‡
0	272,700	111,800
15	—	34,300
30	—	10,840
40	—	1,740
50	106,000	—
60	40,980	—
70	2,690	300
80	270	—
90	46	—
100	58	—
100+1 p.p.m.	6.7	—

* Based on 15-min. demand.
† Demand = 29.3 p.p.m.
‡ Demand = 12 p.p.m.

Grease

A considerable quantity of grease or ether-soluble material passes the baffles and skimmers of the primary sedimentation tanks. This has become a problem of such magnitude that a second set of grease skimmers is to be installed in the secondary sedimentation tanks. The primary sedimentation skimmers are considered to be efficient and the problem is one that will be inherent in compressed air systems.

Los Angeles has a high concentration of home garbage grinders and evidence to date indicates that the grease content of the sewage increases under such conditions. Furthermore, the use of synthetic detergents has increased rapidly and large portions of the increased grease is apparently emulsified and carried in the sewage past the primary skimmers. In the aeration process, a large amount of this material is apparently recoagulated and floats to the surface as finite particles. Grease accumulations are formed on the tank walls and effluent channels and break off almost continually and float to the secondary sedimentation tanks. Grease chunks up to 1 ft. long, 3 to 4 in. wide, and 1 to 2 in. thick are frequently observed. Grease balls up to 6 in. in diameter will build up in the aeration tanks. Apparently, certain types of grease readily build up into balls. The grease accumulations are serious enough to require frequent skimming of the secondary sedimentation tanks.

Synthesized Solids

A characteristic of the high-rate aeration process that had not been anticipated during the design period, is the synthesis of solids from dissolved B.O.D. This apparently takes place during the early part of the typical standard aeration process. However, aerobic destruction of these solids occurs in the later stages of aeration, so no net increase is noted.

In the high-rate aeration process the aerators carry the sewage to the

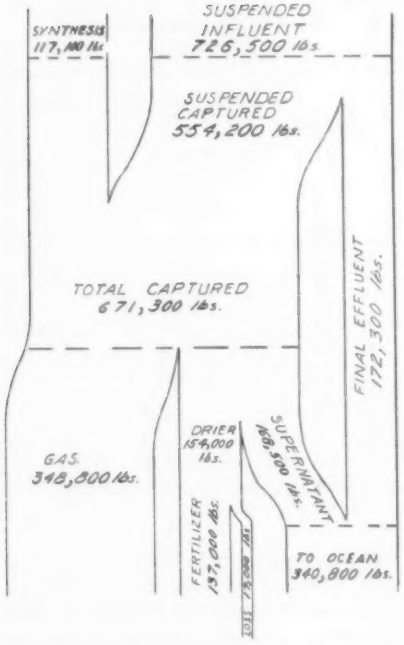

FIGURE 2.—Solids balance, daily average, 1955–56.

synthesis stage only. These synthesized solids settle out in the secondary sedimentation tanks adding substantially to the B.O.D. reduction, but resulting in a solids removal greater than that calculated from the suspended solids analysis of the raw sewage and the secondary effluent. Figure 2 shows the solids balance obtained through the plant during the fiscal year 1955–56.

The synthesized solids (Figure 2) amount to 117,100 lb. per day, or about 18 per cent of the solids removed. This is obviously of considerable significance in the over-all treatment results. It is, however, dependent on the operating condition of the aerators and is, therefore, subject to the instability that seems to be inherent in the high-rate aeration process. The synthesized solids settle quickly in the secondary sedimentation tanks giving good solids and B.O.D. reduction. The secondary sedimentation tanks seem to be sensitive indicators of process performance in that malfunction of the aerators leads almost immediately to bulking and loss of synthesized solids.

Frothing

As with most diffused air plants, frothing and froth control have developed into a problem of considerable proportion. In the Hyperion process, froth cannot be controlled by simply increasing the aerator solids content. The high-rate aeration process must be operated at a low sludge age (0.2 to 0.5 days), and accordingly, the mixed liquor solids cannot be increased beyond the range of 200 to 700 p.p.m.

Froth control is accomplished through the use of secondary effluent water sprays and defrothing chemicals. The water sprays are operated continuously and defrothants are used as necessary. Normally, defrothants are added by a proportioning pump to the water spray system during the hours of 5:00 AM and 1:00 PM, on the schedule of 5 min. on and 10 min. off. On days of severe froth build-up, the defrothant is added to the spray water continuously during the frothing periods. On days of low froth production, spray water alone may suffice.

The physical specifications of the spray system were developed after considerable experimentation. The spray water impinges on the water surface along the side of the tank opposite the air diffusers. A flat spray pattern covering 180° seems to do the best job. The closer the impingement is to the surface of the tank wall, the better the control of froth. However, the spray must hit the water surface.

A spray nozzle is used that delivers 3 g.p.m. at 20 p.s.i. The nozzles are mounted 7 ft. on centers, on a header 2 ft. 9 in. above the water surface, and 15 in. out from the tank edge. In the aerator effluent channels the froth

TABLE V.—Comparison of Several Standard-Rate Activated Sludge Plants

Item	Chicago, Ill.,* West-Southwest	New York, N. Y.,† Wards Island	Los Angeles, Calif.,‡ Hyperion
Aerator influent (p.p.m.):			
Suspended solids	105	94	150
B.O.D.	97	106	130
Final effluent (p.p.m.):			
Suspended solids	15	7	15
B.O.D.	7	6	10
Aeration period (hr.)	4.6	2.7	5.6
Air used (cu. ft./gal.)	0.68	.75	1.51
Cu. ft. air/lb. B.O.D. destroyed	905	900	1,510

* Reference 4.
† Reference 5; step aeration.
‡ Special plant-scale experiment, 1953.

builds up differently, so a slightly different system is used.

For the complete system 5,000 g.p.m. is used over the 9,600 ft. of tank length covered. The spray system cost $83,000 when it was built in 1953. Control of the froth build-up during the treatment of the present flow of 255 m.g.d. costs about $0.17 per million gallons. The annual cost breakdown is as follows:

Defrothant chemical	$ 7,500
Power	5,200
Labor	3,450
Total	$16,150

Since the plant is located where complete froth control is absolutely necessary, this expenditure is deemed to be a reasonable expense.

Odor

The returned seed sludge contains the synthesized solids and is very active biologically. Five-minute oxygen demand determinations show normal oxygen demand levels of 160 to 350 p.p.m. per hour. This high oxygen demand of the sludge, together with a high oxygen demand in the sewage and high average annual temperatures, has necessitated mixed liquor suspended solids control in the range of 200 to 700 p.p.m. (summer and winter, respectively) to keep within the oxygen supply available.

The septic sewage received at Hyperion constantly taxes the high-rate aeration capacity. Complicating the situation is the location of the plant within an odor-sensitive area. Accordingly, operation must be directed toward keeping all odors at a minimum. The high-rate aeration process develops an odor which is slightly less pleasant than conventional activated sludge. Overtaxing of the air supply by increasing the aerator solids causes this odor to approach septicity and increase the problem. The normal aeration odor has caused no difficulty, but there has been ample evidence that process upsets are quickly noted by the neighbors.

In design considerations where odor release is a factor and a stale sewage must be handled, the relatively greater sensitivity of the high-rate aeration process to the release of odors must be considered.

Air Requirements

At an early stage in the operation of the high-rate aeration process, it became evident that a great deal more air was necessary for the Los Angeles sewage than had been predicted from the experience at other cities. To try to obtain a parameter of use for general comparison, experiments with standard-rate operation were made on a flow of 75 m.g.d. in 1953. Table V

shows the comparison between the results obtained at Hyperion and the standard-rate processes at New York and Chicago.

It is apparent from Table V that the results of final treatment at Chicago and New York are almost equal for standard-rate operation. Both plants use about 900 cu. ft. of air per pound of B.O.D. destroyed. At Hyperion it was found necessary to use 1,500 cu. ft. of air per pound of B.O.D. destroyed. The quality of the final effluent was about the same in all cases. Similarly, the high-rate aeration process in New York used about 560 cu. ft. of air per pound of B.O.D. destroyed, whereas it was necessary to use 900 cu. ft. at Hyperion.

Table VI gives operational information on the high-rate aeration process as used at New York and Los Angeles. In addition, the information used for design at Hyperion is shown.

Process Mechanics

Role of Diffusion Equipment

The presently installed air diffusion equipment does not account for the differences noted between the required air at Hyperion and at New York and Chicago. The equipment used is standard for such service and is utilized in part at both New York and Chicago. It is true that the Hyperion studies have indicated that the diffuser equipment may differ in performance efficiency from that at New York and Chicago. However, these differences arise from such factors as the necessity of forcing increased amounts of air through the diffusers giving air utilizations of 4.5 per cent versus the 5 per cent which applies at many other plants and thus indicate efficiency losses of 10 per cent rather than the 60 per cent decrease suggested in the foregoing section.

During investigations into the reasons for the greatly increased air rates noted at Hyperion, considerable attention was directed to the twin problems of the evaluation of present diffuser efficiency and the evaluation of diffuser devices generally.

The majority of the aeration tanks were originally equipped with Saran-wrapped diffusers and one tank was equipped with impingement-type nozzles. At a later date these impingement bowls were removed and a simple sparger nozzle design was substituted. On testing, it was found that both the Saran-wrapped tubes and sparger nozzles exhibited equal treatment efficiencies. The test work has necessarily been aimed at solving a serious treatment problem in which the oxygen demand of the sewage was well beyond

TABLE VI.—High-Rate Activated Sludge *

Item	New York, N. Y.,† Jamaica, Owl's Head, Rockaway	Los Angeles, Calif.	
		Design Basis	Hyperion‡
Aerator influent (p.p.m.):			
Suspended solids	151	146	150
B.O.D.	128	175	150
Final effluent (p.p.m.):			
Suspended solids	40	51	60
B.O.D.	45	69	50
Aeration period (hr.)	1.8	3.2	3.2
Air used (cu. ft./gal.)	0.40	0.51	0.75
Cu. ft. air/lb. B.O.D. destroyed	560	575	900

* Modified aeration.
† Reference 6.
‡ Operations for 1952–54.

that predicted in the design. As a result, the experiences with diffusion equipment have been in the narrow range of aeration rates necessary to meet the specific requirements present at Hyperion. Therefore, the observations regarding the comparative efficiencies of fine-bubble diffusers versus sparger nozzles is at present valid only for the aeration rates used and tested. It has been necessary to apply air on the average of 20 c.f.m. per lineal foot of tank length. Since this is far beyond the range usually used, the comparative efficiency measurements found may not be indicative of results under more normal installations.

Efficiency Measurements

It was soon recognized that any study of aeration system performance needed a method of establishing the oxygenation efficiency of an aeration process. It was also recognized that the method must be applied on a plant-scale basis, as the oxygenation efficiency of an aeration process is affected by such factors as air diffuser placement in the tank (depth, lateral location, and longitudinal distribution), rate of air application, tank turbulence and adequacy of mixing, and the strength of the mixed liquor, in addition to the obvious factor of diffusion mechanism design.

The development of a plant-scale oxygenation efficiency test at Hyperion was based on the oxygen demand concept. The chemical method of determining oxygen demand, as outlined by Kessler and Nichols (7) and Chicago Pump Company (8), was used throughout the work.

Figure 3 shows a typical oxygen demand curve as determined in a Hyperion aerator when the air supply has been increased to a point beyond which no further change in the curve occurs with increased air. The ordinate for the curve is graduated in parts per million per hour (p.p.m./hr.) and the abscissa is graduated, both in tank length and time of travel (hours) from the tank inlet.

This is the fundamental oxygen demand curve for the given sludge-sewage mixture tested. The curve represents the irreducible minimum oxygen demand which exists in the mixed liquor, after the end of the time periods shown, when sufficient oxygen has been made available at every stage of aeration. Regardless of how much excess oxygen is applied to the tank, the mixed liquor cannot utilize it at a rate greater than that shown for each time period. Any excess merely serves to raise the dissolved oxygen level in the tank and does not contribute materially to the aerobic oxidation process.

With this understanding, it becomes apparent that integrating the equation of the curve in Figure 3 will yield the total oxygen demand of the mixed liquor for the time of its detention period in the aerator. This integration is performed graphically by summing the area under the curve. The unit of expression for this summation will be the product of ordinate and the abscissa (p.p.m./hr. × hr.) which equals parts per million. This value, when applied against the known rate of flow of mixed liquor through the aerator,

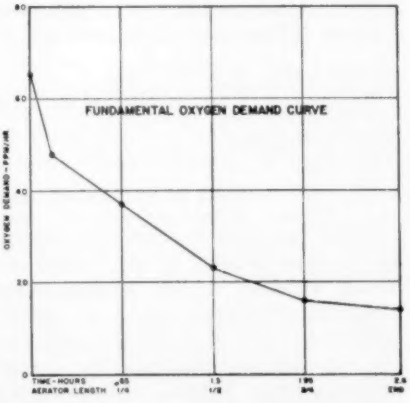

FIGURE 3.—Fundamental oxygen demand curve.

yields the actual weight of oxygen per unit of time which the mixed liquor will demand. An example of the method of calculation is as follows:

1. The area under the curve (Figure 3) is determined by adding the products of successive time periods and average oxygen demand (O.D.) rates.

	Time	Avg. O.D.	
$OD_1 = 0.14 \times$	$\frac{66 + 48}{2}$	=	8.0 p.p.m.
$OD_2 = 0.51 \times$	$\frac{48 + 37}{2}$	=	21.7 p.p.m.
$OD_3 = 0.65 \times$	$\frac{37 + 23}{2}$	=	19.5 p.p.m.
$OD_4 = 0.65 \times$	$\frac{23 + 16}{2}$	=	12.7 p.p.m.
$OD_5 = 0.65 \times$	$\frac{16 + 14}{2}$	=	9.7 p.p.m.
		Summation =	71.6 p.p.m.

2. Any increase in the dissolved oxygen content of the aerator effluent is also considered in order to determine the total oxygen utilized.

Summation O.D.	= 71.6 p.p.m.
D.O. increase	= 1.5 p.p.m.
Total oxygen utilized	= 73.1 p.p.m.

3. The mixed liquor flow rate during the test was 13,200 g.p.m. Using this value, the actual pounds per minute of oxygen utilized may be determined.

$$13{,}200 \text{ g.p.m.} \times 8.34 \text{ lb./gal.} = 110{,}000 \text{ lb./min.}$$

$$\frac{110{,}000 \text{ lb./min.}}{10^6} \times 73.1 \text{ p.p.m.} = 8.05 \text{ lb. } O_2 \text{ utilized/min}$$

Thus far, there has been no quantitative consideration of the oxygen actually supplied to the aerator other than, as previously stated, to supply sufficient air so that further increases do not alter the shape of the fundamental oxygen demand curve as shown in Figure 3. To determine the oxygenation efficiency of the aerator, it is necessary to determine the oxygen utilized and express this quantity as a percentage of the oxygen supplied.

It should be apparent that the fundamental oxygen demand curve also represents the oxygen utilization curve. Figure 4 shows the oxygen demand curves obtained in the aerator for tank air supplies as noted. As the air supply is increased, the curves approach a limiting position which represents the fundamental oxygen demand curve. The other curves in the family represent the oxygen demand existing in the tank under various degrees of insufficient air supply to satisfy the fundamental demand of the mixed liquor.

From Figure 4, the least air flow which will produce the fundamental oxygen demand curve is 10,500 c.f.m. Increases in air flow above this quantity will produce no change in the curve as shown. At an air-flow rate of 10,500 c.f.m., oxygen is being supplied to the aerator exactly as fast as it is being utilized by the mixed liquor.

Knowing the oxygen input and oxygen utilization, the oxygenation efficiency of the system can be computed easily. The method of computation is as follows:

1. Assuming air at 0.075 lb./cu. ft. and 23 per cent oxygen by weight, the oxygen supplied is calculated.

$$10{,}500 \text{ c.f.m.} \times 0.075 \times 0.23 = 181 \text{ lb./min.}$$

2. Using the value of oxygen utilized determined from Step 1, the absolute oxygenation efficiency can be determined.

$$\text{Oxygenation efficiency} = \frac{8.05 \text{ lb./min.}}{181 \text{ lb./min.}} \times 100 = 4.45 \text{ per cent}$$

Maximum Oxygen Demand

The experience with high air rates has indicated certain hypotheses. The

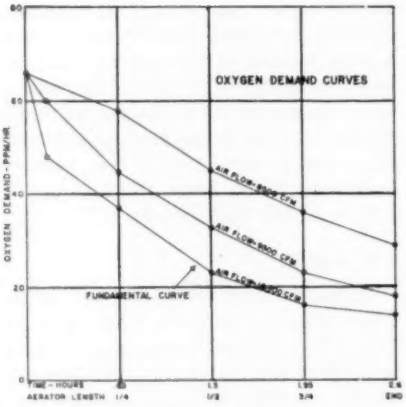

FIGURE 4.—Oxygen demand curves at various air flows.

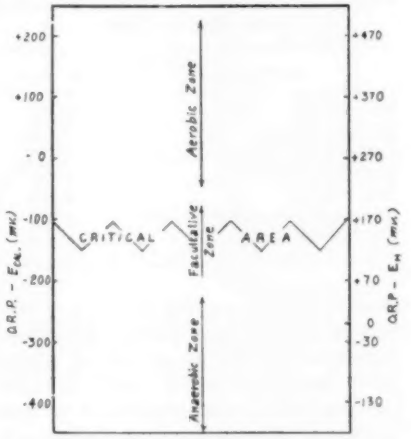

FIGURE 5.—Relationships of oxidation-reduction potentials (Reference 9).

oxygen demand of the sewage ultimately determines the limit of treatability in aeration tanks equipped with the diffused aeration devices currently in use. As the oxygen demand increases, more and more air must be jammed into the head end of a tank to supply the oxygen necessary for treatment. At some point, the oxygen-transfer efficiency begins to drop and adding more air does not help materially. It might be possible to level this out somewhat by adding the incoming sewage over either a portion or the total length of a tank; but in the present Hyperion design an oxygen demand of about 60 to 90 p.p.m. per hour represents the limit of treatment for the equipment. That is, when the mixture of sewage and seed sludge exceeds this demand, the necessary air cannot be supplied and some other method of supplying sufficient oxygen must be considered, such as tonnage oxygen or hydrogen peroxide. This may be a considerable problem in the future.

Treatability

Having established that the efficiency of the air diffusion equipment was of limited significance in the high air rates necessary at Hyperion, consideration was given to the treatability of the sewage itself as a major factor. Operators and engineers have often used the term "treatability" to describe certain types of sewage; but no technical description of this concept exists. Although a formal method of determining treatability has not been developed, it is apparent that the Hyperion sewage is less treatable on arrival at the plant than sewage requiring lower air rates.

It seems obvious that if a sewage is received with some dissolved oxygen content, it will be considerably more amenable to treatment by aerobic means than a very septic sewage. However, it is usual to find that no dissolved oxygen is present; therefore, it is necessary to use some other method of determining the septicity or, alternately, the treatability in an aerobic process. Determination of the oxidation-reduction potential (O.R.P.) appears to be applicable since it is easily measured and has been the subject of a considerable study.

Figure 5 outlines the generalized oxidation-reduction potentials which aerobic or anaerobic processes develop and thus, presumably at which the aerobes or anaerobes function best. It will be noted that true aerobic proc-

TABLE VII.—Oxidation-Reduction Potentials at the Hyperion Plant

Sampling Point	Eh (mv.)
Raw influent	+ 10
End preaeration	+170
End primary sedimentation	+ 35
Start aeration	+150
End aeration	+310
End secondary sedimentation	+290
Start return sludge	− 50

esses operate at an Eh* of about + 200 millivolts (mv.) and above. Anaerobic processes operate at an Eh of about + 50 mv. and below, and facultative organisms exist between + 50 and + 200 mv. Measurements made through the Hyperion plant showed the potentials indicated in Table VII.

Figure 6 presents graphically the oxidation-reduction potentials (Table VII) superimposed on the aerobic facultative and anaerobic zones indicated by Sawyer (9). Except for at the end of the aeration process and in the secondary effluent, O.R.P.'s are in the anaerobic or facultative range. Thus an over-all aerobic system does not exist, and a large percentage of facultative organisms should be present.

This appears to be true since the content of *Zooglea ramigera* in the aerator effluent seems to be very small, or nonexistent, the general culture has a grayish rather than brownish appearance, and the characteristic sludge floc is long and stringy rather than a collection of distinct particles. This sludge floc does settle rapidly and good solids and B.O.D. reductions are obtained.

If a raw sewage with a dissolved oxygen content or with an Eh characteristic of the high facultative range were being received, it seems apparent that an aerobic environment could be maintained much more easily throughout the system. The high septicity of the Hyperion raw sewage, as indicated by the depressed O.R.P., means that a great portion of the aeration capacity must be utilized to bring the sewage from the anaerobic to the aerobic range where facultative or low aerobic cultures can be developed. This pre-pretreatment is the basic problem, and is not usual for most plants.

Preaeration

A careful and detailed study of the preaeration system was made as it affected the primary sedimentation effluent. One-half of the sewage flow was given preaeration, while the other half received none. The primary sedimentation effluent from the preaerated half was the same as the effluent received from the unpreaerated half insofar as B.O.D., suspended solids, settleable solids, and chlorine demand reduction were concerned. Preaeration did reduce the sulfide content somewhat, thus reducing the oxygen demand of the aerator influent a small degree. It is doubtful that the slight reduction in oxygen demand justifies the use of air for preaeration, and it is felt that the air would be used to better purposes in the aerators. In contradiction to this, preaeration has apparently been of value in other installations.

It is believed that the concept of treatability can help to explain why preaeration works at some locations and fails at others. Preaeration of sewage which is only slightly septic and has a low to moderate oxygen demand might keep the sewage in the high facultative to low aerobic range, preventing anaerobic breakdown, and thus decrease the load on the aerators. However, where the septicity is far advanced and the oxygen demand is high, a short preaeration period cannot meet the oxygen demand, and the little good accomplished by preaeration is quickly nullified by further anaerobic degradation in the primary sedimentation tanks.

* Eh is the potential an unattackable metal electrode assumes in a solution relative to that of the normal hydrogen electrode.

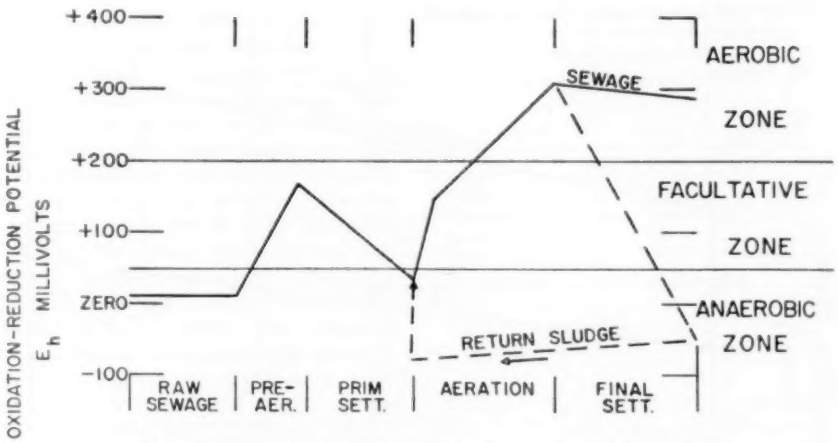

FIGURE 6.—Oxidation-reduction potential survey at Hyperion.

Oxygen Demand

Although the mixed liquor has a relatively high oxygen demand (Figures 5 and 6) on entering the aeration tank, much of this is satisfied as the sewage passes through the aeration process. In many plants it is common to find the incoming mixed liquor with an oxygen demand of 30 to 40 p.p.m. per hour and an aerator effluent oxygen demand of from 5 to 6 p.p.m. per hour. At Hyperion, the incoming mixed liquor is more likely to show an oxygen demand of from 50 to 90 p.p.m. per hour with an effluent oxygen demand of 10 to 20 p.p.m. per hour.

Since the mixed liquor is composed of two active biological media (returned seed sludge and sewage) it is fairly obvious that the observed oxygen demand contains at least two components. Sawyer and Nichols (10) pointed out that when the oxygen demand or oxygen utilization of a mixed liquor is plotted against the seed-sludge solids content, a linear function is obtained which shows some oxygen utilization at zero solids content. They believed this oxygen demand at zero solids is due to the sewage itself.

Solids

Figure 7 is a plot of some of the Sawyer and Nichols data, covering the range of mixed liquor solids commonly used in the Hyperion high-rate aeration process, together with a plot of the values normally obtained at Hyperion during summer and winter months. Although the slopes of all curves are approximately parallel there is an initial oxygen demand of 30 to 50 p.p.m. per hour as compared to the 2 to 7 p.p.m. per hour of the Wisconsin sewage reported by Sawyer and Nichols (10).

The fact that an oxygen demand of 30 to 50 p.p.m. per hour, attributable to the sewage itself, exists at the point of zero returned sludge solids is of significance. It shows that the sewage reaching the plant before inoculation with the aerobic or facultative return sludge organisms has a demand in excess of the mixed liquor demand of many other plants. Thus, the use of 900 cu. ft. of air per pound of B.O.D. destroyed, versus 560 cu. ft. for New York, becomes somewhat more understandable. Furthermore, manipulation within the plant processes themselves

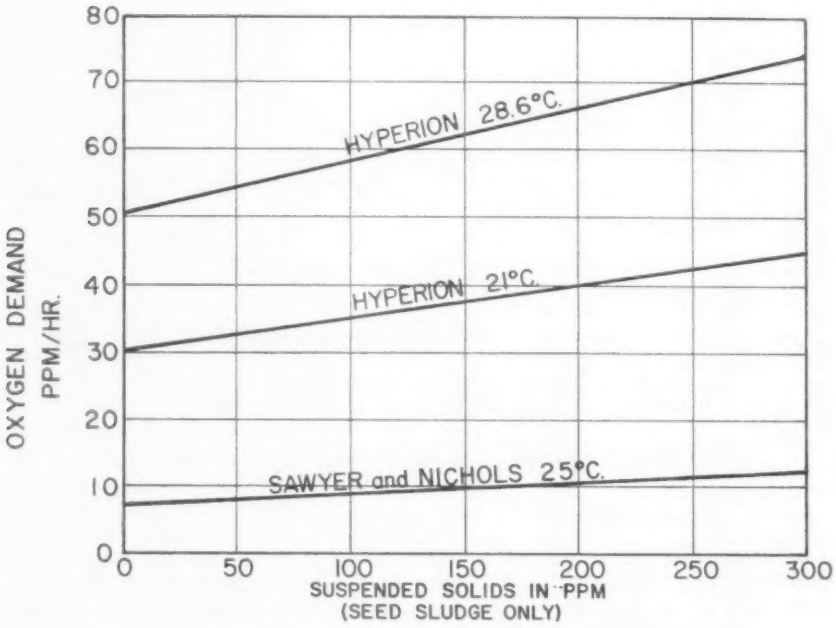

FIGURE 7.—Oxygen demand versus seed sludge concentration.

is not responsible for the high air-use rate. A large amount of air must be added just to bring the sewage to a point where many plants start their treatment.

Effective B.O.D.

One possible contributing factor for the high oxygen demand of the sewage lies in the effective B.O.D. concept outlined by Pomeroy and Bowlus (11). They stated that the effective B.O.D. actually operating in a biological system, such as the sewer or treatment plant, was a function of the temperature, and could be represented by the equation

$$\text{Effective B.O.D.} = (\text{5-day } 20^\circ \text{ C. B.O.D.}) \times (1.07)^{T-20}$$

in which

T = temperature in °C.

Thus, at higher temperatures the organisms are more active, reactions can occur more rapidly, and a greater amount of the first stage value of the B.O.D. is available. This corresponds, in effect, to treating a stronger sewage. Table VIII illustrates this by showing the effective B.O.D. of a raw sewage with a 240-p.p.m., 5-day 20° C. B.O.D. at the annual average Hyperion sewage temperature, versus the effective B.O.D. that this same 240-p.p.m., 5-day 20° C. B.O.D. sewage would have at the annual average temperature in Cleveland, Ohio, Chicago, Ill., Milwaukee, Wis., and New York, N. Y.

From Table VIII a sewage having a nominal 5-day 20° C. B.O.D. of 240 p.p.m. would have an effective B.O.D. of 304 p.p.m. at Hyperion, whereas the other plants shown would have B.O.D.'s of only 160 to 225 p.p.m. This represents an increase over the indicated B.O.D. at Hyperion of about 27 per cent, and a decrease of from 7 to 35 per cent at the other plants.

Effect of Outfall Sewer

A factor probably included in the effective B.O.D. measurement is the fact that the average flow time from the sewerage system to the plant is 8 hr. With the high annual average temperature and the active biological system present in the Los Angeles sewers, the sewage is quite septic on reaching the plant. Thus, partial anaerobic digestion has occurred and compounds more immediately available for oxidation are present. The dissolved 5-day 20° C. B.O.D. of the raw influent is 105 p.p.m. This value is believed to be somewhat above normal and the breakdown during the process of becoming septic may be a significant contribution to this total.

The dissolved sulfide content of the sewage increases from 0 p.p.m. to as much as 2.5 p.p.m. over the last 9 miles of sewage flow, as a result of biological processes. This sulfide ion content represents a significant instantaneous load on the treatment processes. Upsewer sulfide control measures might substantially aid aeration, but such methods are generally expensive.

There are undoubtedly other factors of importance; but it becomes clear that a trunk sewer must be considered as a part of the treatment plant no less than the sedimentation and aeration tanks themselves. Active biological processes are in operation and the effect is of major importance on such factors as air demand and aerator performance. The Hyperion problem is compounded by the relatively high sewage strength and high annual average temperature since bacterial activity is accelerated under such conditions.

At present about 80 per cent of the 255-m.g.d. flow to the Hyperion plant comes through a single trunk sewer. A significant oxygen demand develops prior to the entrance of the sewage into this trunk, but a substantial amount develops in the final 9 miles of combined flow to the plant.

The sewer has a 12.5-ft. semi-elliptical section and was originally lined with clay tiles set in sulfur-silica cement as a protection against sulfide corrosion. At peak flow periods, sewage velocity through the last 9 miles is 4.78 f.p.s. At low flow periods, the velocity is 4 f.p.s. A number of the protective tiles have fallen off during the years and it is felt that these and sand may have accumulated on the invert, in spite of the velocity, to make an excellent environment for the biological systems that are found in sewer slimes.

TABLE VIII.—Effective B.O.D. of a 240-P.P.M. 5-Day 20° C. B.O.D. Sewage at Various Temperatures

Location	Average Annual Sewage Temp.* (° C.)	Effective B.O.D. (p.p.m.)
Hyperion, Calif.	23.5	304
Cleveland, Ohio	13.7	157
New York, N. Y.	19.0†	224
Milwaukee, Wis.	16.2	185
Chicago, Ill.	16.0	183

* Data from annual reports.
† Reference (12).

The slimes are a constant source of seed to the sewage (13) and contribute heavily to the bacterial action that leads to degradation and high oxygen demands. The substantial velocity at various times of the day should be noted since significant sulfide build-up and degradation occurs in spite of the indication from studies by Pomeroy and Bowlus (11) that the velocities are adequate to prevent a sulfide increase.

Table IX illustrates the importance of slimes and their function as biological seed. To obtain these data, a sample of sewage was taken from the main outfall sewer 9 miles upstream from the plant. The sample was placed in a clean 5-gal. glass bottle and stoppered so that no air was trapped. The sample was then taken to the laboratory and kept under gentle agitation until a sample of the same sewage which had

TABLE IX.—Degradation of Sewage During Flow Through Los Angeles Outfall Sewer

Item	Sewer Sample*	Plant Sample
Sampling point (ft.)	47,365	Hyperion
Sampling time (hr.)	14:05	16:45
Sample analyzed	16:45	16:45
Temp. (° C.)	26.7	27.2
Solids (p.p.m.):		
Total	1,610	1,350
Dissolved	1,180	1,050
Suspended	430	300
B.O.D. (p.p.m.)	342	282
Eh (mv.)	+273	+63
Dissolved oxygen (p.p.m.)	0	0
Sulfides (p.p.m.):		
Total	0	1.3
Dissolved	0	1.2
Oxygen demand (p.p.m./hr.):		
Organic	10.6	37
Total	27.0	58.8
Chemical or immediate	16.4	21.8

* Upstream.

travelled through the sewer to the plant had been obtained. The two samples were then analyzed as shown in Table IX.

The sample obtained after flow through the sewer showed a substantial increase in the degree of degradation as measured by the O.R.P., sulfides, and oxygen demand and, therefore, a decrease in the treatability of the sewage received at the plant. The sample from the sewer at the plant influent showed a shift in the Eh towards the anaerobic range, an increase in dissolved sulfides, and a substantial increase in oxygen demand. However the B.O.D. value and solids content indicated that the sewage which had flowed through the sewer to the plant and that which had been placed in the glass bottle should be equally amenable to treatment. A treatment problem in the form of a substantial load on the aeration process had developed and the usual indicators did not show this. When aeration is to be utilized, more complete information is apparently necessary.

Based on the information reported in Table IX, it was decided to study further the increase in oxygen demand occurring in the final 9 miles of flow to the plant. Subsequently the change in oxygen demand was measured over a 7-day period. Duplicate analyses were made on each day. The analytical technique was similar to that used to develop Table IX.

Samples were obtained in clean 5-gal. glass bottles over a 15-min. composite period at the upstream manhole. The oxygen demand and O.R.P. of the sewage sampled were determined immediately. After a period correspond-

TABLE X.—Change in Oxygen Demand and O.R.P. During 9 Miles of Sewer Flow

Date (Oct., 1956)	Time (hr.)	O.R.P., Eh (mv.)			Oxygen Demand (p.p.m./hr.)					
		Upstream Sample		Hyperion Sample	Upstream Sample				Hyperion Sample	
					T = 0		T + 165 min.		T + 165 min.	
	T = 0	T = 0	T + 165 min.	T + 165 min.	Organic	Total	Organic	Total	Organic	Total
3	12:30	+253	+253	+ 91	10.2	20.3	29.9	44.5	39.0	43.1
4	12:30	+253	+253	+ 73	16.0	16.1	29.5	32.2	43.2	43.2
5	12:20	+253	+259	+157	12.0	12.0	21.3	21.3	35.0	35.0
15	12:30	+271	+163	+ 91	—	—	—	—	—	—
16	12:40	+253	+235	+ 31	34.0	34.0	29.4	37.6	21.2	24.0
17	12:30	+247	+235	− 17	43.4	43.4	22.9	25.6	43.4	44.9
18	12:30	+259	+157	− 35	19.6	19.6	17.0	17.0	37.5	37.5
Avg.	—	+256	+222	+ 56	22.5	24.2	25.0	29.7	36.6	38.0

ing to the sewer flow-travel time, a sample was obtained at the plant influent using a similar sampling technique. The upstream sample and the sample collected at the plant influent were then analyzed for oxygen demand and oxidation-reduction potential. The upstream sample was kept as close to sewer temperature as possible and was gently agitated during the flow time. Oxygen demand is reported (Table X) as organic and total, the latter including the immediate, sulfide, or chemical demand.

The average values of Table X show that the degradation of the sewage in the trunk sewer directly upstream from Hyperion is substantial, and that such a decrease in treatability is apparently characteristic of that portion of the sewer. Thus, during the final 9-mile length of the major outfall, an average decrease of 200 mv. was measured in the O.R.P. and an average increase of 57 per cent (14 p.p.m. per hour) was registered in the oxygen demand during the test period.

Other data indicate that these actual values may increase or decrease with the seasons and with the sewage characteristics; but that the general pattern holds. The data of Table XI tend to further support these conclusions. On the other hand, the corresponding samples held in the clean glass bottles for the time interval equivalent to the flow period from the sampling point to the plant showed little, if any, further degradation. The changes shown by the upstream samples may have resulted from variances in the analytical method.

It is believed that biological organisms capable of causing degradation occur in the free flowing sewage stream and would be caught in any sample removed. However, their concentration is small and the effect of their action is slight, so the net change is masked by normal variances in the analytical techniques. On the other hand, the biological systems of the

TABLE XI.—Average of Five Sampling Runs Made Over the Lower 9 Miles of the Principal Outfall to the Hyperion Treatment Plant

Sampling Point		Flow (m.g.d.)	Flow Time to Plant (min.)	Distance to Plant (ft.)	pH	Temp. (° C.)	Solids (p.p.m.)			D.O. (p.p.m.)	B.O.D., 5-Day 20° C. (p.p.m.)	O.R.P., Eh (mv.)	Sulfides (p.p.m.)	
No.	Location						Total	Dissolved	Susp.				Total	Dissolved
1	Duquesne and Jefferson	200	165	47,356	6.8	28.5	1,186	960	226	0	284	+258	0.8	0.2
2	Centinella Siphon Inlet	200	117	33,231	7.0	28.5	1,186	949	239	0	271	+122	1.5	0.6
3	Manhole 15	200	65	20,100	7.0	28.5	1,246	975	271	0	262	+70	2.0	1.1
4	Manhole 19	215	52	16,430	7.0	28.2	1,258	1,050	208	0	257	+50	2.1	1.2
5	Hyperion Plant	253	0	0	7.2	28.3	1,286	1,063	223	0	276	+48	2.6	1.8

sewer wall slimes are well established and concentrated so that major changes in the over-all sewage condition occur. The net effect of flow through the sewers is thus to aggravate the tendency towards septicity and poor treatability. Also, it is apparent that the sewage 9 miles upstream would be easier to treat in an aerobic process.

To evaluate further the effect of the biological systems operating on the sewage in the main trunk sewer, an attempt was made to follow a portion of sewage through the last 9 miles of flow. The flow time between certain key manholes was determined and on five separate days, covering the month of August, 1956, a portion of sewage was followed.

Samplings were made according to the flow time and immediately analyzed. The experiment was somewhat hampered by the fact that between the third and fourth sampling points a trunk sewer discharged about 15 m.g.d. to the main flow and between the fourth and fifth sampling points a separate trunk discharged an additional 38 m.g.d. The effect of these side flows on the data was apparent.

Evaluations were made of the B.O.D., solids, O.R.P., dissolved oxygen, and sulfides. Oxygen demand analyses were attempted, but it was found almost impossible to keep an aerobic seed sludge with known characteristics available at each sampling station. The range of changes measured in the seed sludge could cause a greater increment in the oxygen demand than indicated in Tables IX and X. These data were therefore considered to be unusable, although they did generally confirm the pattern of Tables VIII and IX.

Analysis of the information in Table XI indicates that it supports the conclusions drawn from Tables IX and X. Thus, the dissolved oxygen, temperature, pH, suspended solids, and B.O.D. changed very little, if at all, during the test period, while the sulfide and O.R.P. data indicated steady deterioration. Using the solids and B.O.D. data alone, it could be concluded that the sewage at Points 1 and 5 are equally amenable to treatment. However, using the O.R.P. and sulfide data, and referring them to the relations shown in Table IX and Table X, which indicate a coincident increase in oxygen demand, it can be seen that serious degradation occurred.

The material presented in Tables IX, X, and XI shows that a portion of the trunk sewer is definitely a part of the treatment problem and must be considered in operation as another, and in this case probably unwanted, treatment unit. The serious increase in the oxygenation load represented by the sewer is well in excess of that considered in the plant design, and is probably forgotten in most design considerations.

Recommended Study

A study of the basic treatability of a sewage is considered to be of great significance in any treatment plant design program that contemplates any form of oxygen stabilization. In an existing sewage system certain minimum studies should be made to permit design factors to be set with greater confidence. The analyses outlined in Table IX should be made in each case. The analyses suggested are all standard, with the oxygen demand test being the only one requiring special considerations. However, the oxygen demand of the sewage is of primary importance for any aeration process; therefore, it must be determined. It is believed that had such tests been made prior to the construction of the aeration system at Hyperion, an air usage of 0.8 cu. ft. per gallon could have been predicted, rather than the 0.5 cu. ft. per gallon provided in the design for maximum flow and strength conditions. Providing adequate capacity originally is much easier than adding it later.

TABLE XII.—Oxygen Demand of Unaerated, Stored Raw Sewage

Storage Time (min.)	Oxygen Demand (p.p.m./hr.)
0	60
3	48
6	46
16	56
60	59
120	44

TABLE XIII.—Oxygen Demand of Cultured, Aerated, Stored Raw Sewage

Ratio Aerobic Sludge to Raw Sewage	Ratio Dilution Water to Sludge-Sewage Mix	Storage Time (min.)	Oxygen Demand (p.p.m./hr.)
1:7	3:1	2	90
1:7	3:1	5	41
1:7	3:1	15	34
1:7	3:1	30	31
1:7	3:1	60	24
1:7	3:1	120	12

An oxygen demand study of an existing sewer system calls for some planning but it is not a difficult procedure. The chief requirements are a quantity of aerobic sludge or mixed liquor and the chemicals outlined by Kessler and Nichols (7). The chemicals are standard and can be purchased easily, but the sludge may have to be developed.

A suitable aerobic sludge can be produced in a 55-gal. drum filled with sewage and raw sewage-sludge and continually aerated or mixed mechanically for a week, adding 35-per cent hydrogen peroxide at the rate of 1 to 2 qt. daily. The original solids content in the drums should be approximately 4,000 p.p.m.

The aerobic sludge must be provided since the oxygen demand of the sewage is made up of the immediate or chemical demand, and an organic demand which must have aerobic seed organisms present to allow the oxygen to satisfy the demand. The oxygen demand is essentially a short term B.O.D. and, although it is present in raw sewage, it would not be apparent if a demand test were made in which no aerobes were present. The effect of the raw sewage on an aerobic system is what is being studied, and the portion of the B.O.D. made quickly available by aerobic organisms must be determined.

During the investigation of the oxygen demand or short term B.O.D. of raw sewage, several experiments were attempted to evaluate the oxygen demand test itself. In the first of these, a quantity of sewage was held for a 2-hr. period in a clean bottle with non-aerating mixing. The oxygen demand rate over a 5-min. period was determined at intervals during the 2-hr. storage time. The data are given in Table XII.

Thus within the inherent variation in the test no change in oxygen demand occurred during the 2-hr. holding period. It was apparent that a clean glass bottle with no slimes causes little further degradation.

The second test involved setting up the oxygen demand test by the dilution bottle method and leaving the sewage-sludge mixtures in contact with the dilution water for various periods up to 2 hr. Thus the demand rate in parts per million per hour over the period from 2 min. to 120 min. was found. The data are shown in Table XIII.

The variation in the oxygen demand rate exhibited after various periods is clearly shown, and the importance of using a single contact time in any comparative study is emphasized. In the work reported herein, a 5-min. contact time was used and comparisons are made on that basis.

Summary

The high-rate aeration process has been in successful operation at the Hyperion Treatment Plant since 1951. During this period removal of the suspended solids and B.O.D. has ranged from 75 to 85 per cent, and polishing

chlorination has been practiced economically. The aeration units themselves are doing an excellent job, although primary sedimentation removals averaged 28 per cent for suspended solids and 15 per cent for B.O.D., compared to an additional removal in the secondary treatment section of 54 and 65 per cent for suspended solids and B.O.D., respectively.

The high-rate aeration method is inherently unstable and necessitates close and accurate process control. However, the degree of treatment accomplished seems to be relatively independent of the raw sewage strength and the effluent is similar enough to a standard-rate effluent to allow good organism kills by chlorination.

Operationally, the high-rate aeration technique and diffused air aeration in general have introduced factors not considered in the original design of solids, such as the synthesis from dissolved B.O.D. in the aerators equal to 18 per cent of the total solids. These solids settle rapidly in secondary sedimentation and contribute materially to treatment efficiency. However, they produce a very active, hard-to-handle return aerator seed sludge. They are also subject to the instability of the high-rate aeration process itself, and secondary sedimentation bulking is a sensitive indicator of process upset.

Grease developed as a major problem as a result of garbage grinders and other changes which introduced more fats and oils into the sewers. These are emulsified by the synthetic detergents and by-pass the baffles and skimmers in the primary sedimentation tanks. Desolubilization or demulsification occurs on aeration, and significant amounts of floating grease appear in the final sedimentation tanks.

Frothing has also been a major problem, with control by aerator solids being impossible. Control has been effectively accomplished by water sprays and the addition of defrothant at an operating cost of $0.17 per million gallons.

Air requirements at Hyperion were greatly in excess of design provisions and were 60 per cent or more in excess of air requirements at similar plants. The air diffusion devices contributed only slightly to the difference noted in the aeration rates, although at 20 c.f.m. per lineal foot (average aeration rate) and 36 c.f.m. per lineal foot (maximum rate) no difference in efficiency was noticed between sparger type aeration nozzles and fine bubble diffusers.

A method was developed for computing the absolute oxygenation efficiency of a system. The air added to a tank was varied until further additions showed no further reduction in the oxygen demand curve and, thus, no further air utilization. At this point it was considered that the oxygen demand and oxygen utilization were the same. From the oxygen demand curve the efficiency was calculated. With this method oxygenation devices can be compared. As a hypothesis—the treatment capacity of any aeration system is limited by the oxygen demand of the mixed liquor. At Hyperion, the present units limit the oxygen capacity to 60 to 90 p.p.m. per hour. Thus, air cannot be crammed into a tank in sufficient volume to treat a waste whose oxygen demand exceeds the oxygen capacity of the aerators.

The heavy air demand stems almost entirely from the raw sewage characteristics. The term "treatability" has been used to summarize the effects of the raw sewage characteristics. The manipulation of plant processes produces very little change.

The poor treatability of the Hyperion raw sewage is shown most clearly by the oxidation-reduction potential (O.R.P.) and the oxygen demand characteristics. The O.R.P. is characteristic of an anaerobic biological system and the 5-min. oxygen demand varies from 30 to 50 p.p.m. per hour. Reasons for the high oxygen de-

mand are: (a) the high effective B.O.D. and (b) the anaerobic biology of the outfall sewer to the plant which causes partial digestion and substantial sulfide build-up.

The average flow-time of 8 hr. to the plant and the high average annual temperature are also important factors contributing to the septicity of the sewage.

Preaeration has been of virtually no value at this plant other than for corrosion control. Where only a slight raw influent degradation is present, preaeration might be quite desirable.

The biological activity in the trunk sewers tributary to Hyperion can be considered as much a part of the treatment plant as the aeration tanks themselves. It is recommended that studies of an existing sewerage system be made as a part of any plant design scheme. In such a study the oxygen demand, oxidation-reduction potential, and sulfides should be determined as a minimum analysis. As a result, treatment unit demands could be more accurately predicted in planning.

Conclusions

The studies of the aeration process at the Hyperion sewage treatment plant have resulted in the following conclusions:

1. The high-rate aeration process has produced an effluent that is relatively independent of the strength of the raw sewage. Suspended solids and B.O.D. removals of 75 to 85 per cent are achieved with about 65 to 73 per cent of the removal occurring in the aerators.

2. The high-rate aeration method suffers from a basic instability and requires close and careful process control for best operation. However, an effluent of good quality susceptible to chlorination can be developed.

3. Approximately 18 per cent of the solids removed are synthesized in the aeration units from dissolved B.O.D. These synthesized solids are active biologically and contribute to the process instability.

4. The grease content has increased and substantial portions have been emulsified by the synthetic detergents in the sewage. These solids are carried past the primary skimmings baffles, reconstituted to a degree upon aeration, and appear as a skimmings problem in the secondary sedimentation units.

5. Frothing and froth control have developed into a serious problem. In a high-rate aeration system solids control cannot be utilized; accordingly, water sprays and defrothants have been successfully used.

6. Air demands were 60 per cent greater than those at other similar plants. The diffusion equipment and other plant devices did not account for this difference. Aeration rates were 20 to 36 c.f.m. per lineal foot of tank, and sparger type nozzles and fine bubble diffusers were found to be equal in performance.

7. With the presently available tanks and diffusion equipment, a mixed liquor with a constant oxygen demand of 60 to 90 p.p.m. per hour represents the limit of treatability. Beyond this range oxygen cannot be transferred to the liquid in sufficient volume to maintain treatment. High-purity oxygen or other sources of oxygen might be needed.

8. The high air demand results almost entirely from such factors as: (a) 8-hr. average raw sewage flow time to the plant, (b) average annual sewage temperature of 23.5° C., (c) O.R.P. with an Eh of 40 to 50 mv. (anaerobic), and (d) oxygen demands of 30 to 50 p.p.m. per hour.

9. Preaeration gave very little benefit insofar as treatment was concerned and the air could be more beneficially used in the aeration tanks. The incoming raw sewage carried such a heavy oxygen demand that preaeration could not meet it and rapid anaerobic degradation continued in the primary sedimentation units.

10. The reasons for the sewage characteristics leading to poor treatability are not entirely clear. The following are felt to be of major importance:

The effective B.O.D. is such that treatment must handle an average of 27 per cent more B.O.D. than the indicated 5-day 20° C. B.O.D. Comparative plants treat about 7 to 35 per cent less B.O.D.

The high average temperature and long flow time lead to septic sewage. Thus, more of the B.O.D. may be readily available as oxygen demand.

Substantial dissolved sulfide buildup occurs with consequent immediate oxygen demand.

11. The biological processes operating in tributary trunk sewers should be considered as much a part of the treatment plant as the aeration tanks or primary sedimentation units. Studies of sewage characteristics should be made a part of any design consideration on a secondary plant.

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DISCUSSION

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The paper by Bargman *et al.* states a fact that is sometimes overlooked by planners and operators of sewage treatment facilities. That is that sewage starts to treat itself voluntarily and irrespective of the starting mark established by the designer at the headworks of the treatment plant. The commencement of biochemical change up-sewer, where treatment process control is impossible, created operating problems not anticipated in the Los Angeles design. The well-known sensitivity of the activated sludge process and its variations combines with the conditions embraced by the newly-interpreted treatability term explained by the authors to impose limitations which are insurmountable in the present Hyperion installation without plant, process, or equipment changes.

The assignment of something more specific than a generalized significance to the term "treatability" is a progressive step toward identifying the component criteria of any sewage treatment process. The use of the oxidation-reduction potential for this purpose has found prior application in a comparable study. Brown and Caldwell, in a series of determinations of the relationship between oxidation-reduction potential and aeration period on San Jose, Calif., sewage, concluded that relative stability of the Eh value occurred after about 30 min. of preaeration. Their findings also indicated the point where such stability became manifest was in the range of an Eh of 200 to 300 millivolts. This would lend additional credibility to the critical range values of 50 to 200 millivolts, as cited by the authors from work done on Los Angeles sewage by Sawyer (1).

The aforementioned San Jose work was executed in studies to assess the effectiveness of preaeration to minimize scum formation in primary sedimentation basins during the food-processing season, which was expected to be the critical one for the then-proposed San Jose sewage treatment plant. The conclusion reached from those studies was that aeration for 20 to 30 min. was sufficient to cause suspended matter to settle as sludge and to prevent subsequent rising for a period of 3 to 4 hr. or longer. The results conclusively indicated that 60 min. of aeration was necessary on that sewage to obtain an oxidation-reduction potential which did not decline during the subsequent period of sedimentation. That stability was felt to be desirable and probably necessary to insure against rising of sludge which could be retained in the primary sedimentation basins for more than 4 hr.

The historic use of dissolved oxygen as a parameter of aeration tank condition, and to control the performance of the activated sludge process, is shown to have valid connotation by the relationship of declining oxygen demand and aeration time. It would appear reasonable to state that, as long as dissolved oxygen is present, it is in a form and quantity available for take-up—either biological or chemical—hence as an operating yardstick it is a simplified tool to use in lieu of the oxidation-reduction potential and to achieve the aerobic environment demanded by the process.

The authors point to the trunk sewer as the site of anaerobic fermentation prior to arrival at the plant. This lends substance to the interest shown in preaeration in various parts of the country in recent years. Through the use of this pretreatment method, at least partial transition of the sewage organisms from the facultative zone to the aerobic zone, as described by

Sawyer (1), may be accomplished, thus conditioning the sewage for more effective succeeding biological treatment, or improving its treatability.

The Walla Walla, Wash., sewage treatment plant may serve as an example of the restoration of a declining dissolved oxygen content to improve the sewage treatability in a two-stage trickling filter plant. Preaeration is used to raise the dissolved oxygen in the primary sedimentation basin effluent, thus keeping the following roughing filter feed aerobic. In this manner, filter recirculation can be reduced without any effect on the biological loading on that filter and without any adverse effect on its biological efficiency. Additional cost of air is partially offset by a reduced cost of recirculation pumping, so the net increase in power cost for the last report year was $0.80 per million gallons.

The inefficiency of the air diffusion methods in current vogue is once more emphasized for further consideration. For example, the maximum oxygen demand capable of being satisfied by the two types of aeration facilities at Hyperion is stated to be about 90 p.p.m. per hour. Using the 11,000 c.f.m. air rate and 20 per cent oxygen in the air used, the total oxygen supplied is 9,900 lb. per hour, indicating 4.65 per cent efficiency.

Since oxygen utilization by organisms depends upon its availability in the dissolved state and since this state depends upon absorption from the overlying atmosphere and the diffused air bubbles, the oxygen used must traverse the air-sewage interface and be controlled by the respiration rate. Hence it is subject to the physical and biological constants affecting each transition. Thus, increasing the rate of oxygen absorption from air to mixed liquor may not have any effect on the rate of utilization by the respiratory processes of the organisms. Similarly, any means for increasing the utilization rate, such as temperature increase, might be futile if the rate of absorption from the atmospheric air is less. The authors imply that air-to-sewage transfer is more critical in order to keep the aeration capacity within the process demands. This, then, redirects attention to another aspect of the basic problem at Hyperion; namely, efficiency of oxygen absorption by the mixed liquor.

Whether the answer may be wholly or partially found in such methods and materials as pressure aeration, tonnage oxygen, cavitation effect, improved diffusers, or other means seems uncertain at present. The mechanical problems of conceiving a fine-diffusing medium or process that is clog-free have yet to be solved although some new equipment developments may hold the answer.

Whether it is perceiving new relationships or in pointing out old ones from new points of view, the Hyperion staff has upheld its record of contributing solidly to the knowledge of sewage treatment.

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Industrial Wastes

UNDERGROUND MOVEMENT OF RADIOACTIVE WASTES *

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The transport of radionuclides by the subsurface waters of the earth has an important bearing on the environmental hazard created by the waste fission products of the nuclear energy industry. The alternative systems for handling the wastes of this industry are limited to confinement and dispersal. Unfortunately, the extremely small concentrations of the more hazardous radioisotopes permitted in drinking water essentially preclude disposal by dilution of any but the lowest-level wastes and of relatively small quantities of such isotopes as strontium-90. Nuclear industries located in arid regions of the West often have no surface dilution water available to them and may be required by apprehensive regulatory agencies to produce an effluent completely devoid of radiocontaminants. Under these circumstances, conventional methods of dispersal are not feasible, and complete confinement, perhaps preceded by a concentration process, represents almost the only solution.

In situations involving high-level wastes containing up to several hundred curies per gallon, prolonged storage is an unavoidable aspect of chemical processing and must precede any final containment. Under these circumstances there exists the possibility of accidental contamination of potentially useful ground water. An investigation of this potential hazard obviously must be an integral part of a site-selection study, particularly as a competitive nuclear industry faces the necessity of locating its plants near population centers.

Where small volumes of low- or intermediate-level wastes are produced, concentration of the radioactive fraction before storage is indicated. However, larger volumes of such wastes pose a costly problem in volume reduction, particularly if stringent effluent requirements are to be met. Under these circumstances, underground formations of the earth represent an attractive storage or retention resource worthy of consideration. Although this method of disposal is not without precedent, the disadvantage of a system entailing the free discharge of a hazardous material into the ground is obvious. The most serious objection evolves from the uncertainty as to where and when the radioactive material will appear in the water supply of some community. In spite of this admitted possibility, the great capacity of the material of the earth to adsorb trace concentrations of radioelements strongly indicates the desirability of investigating methods of ground disposal.

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Ground Disposal Systems

In designing a free-discharge disposal system, the probability of contaminating potentially useful ground or surface water must be reduced to an absolute minimum. Systems most nearly meeting this criterion appear to fall into either the spreading or injection category.

Spreading

Surface or subsurface spreading systems are indicated where the groundwater table is overlain with several hundred feet of unconsolidated media and the local precipitation is low. The ion exchange capacity of the earth column serves to retain the cationic waste components and, if additions of liquid cease when the most rapidly moving hazardous component reaches the zone of saturation, a highly permanent retention is achieved. Important considerations in the design of such a system include (a) the infiltration capacity of the surface strata, (b) the formation permeability and its variation with direction and distance, and (c) the exchange capacity for the more hazardous radioisotopes.

Injection

The second type of disposal system consists of the injection of the wastes into deep formations, well below the zone of circulating or meteoric waters. Deep sedimentary formations generally contain connate, or fossil, water that has migrated relatively little over geologic time. The interstitial space of such connate-water bearing sands may well constitute a far more permanent natural container than man has yet devised. Furthermore, the exchange capacity of many connate formations will contribute greatly to the storage capacity and permanence of this natural container.

Design Considerations

The design of disposal systems of the injection type requires compatability of the waste and the media of the disposal site; there must be an absence of particulates and precipitate-forming chemicals. With this criterion met, it is then necessary to predict the direction and velocity taken by the various radiocomponents.

The direction and average velocity are determined by the hydraulic gradient and porosity, and, when the medium is unsaturated, by the existence of capillary forces. The occurrence of longitudinal mixing or hydraulic dispersion results in some portions of the waste traveling at velocities considerably greater than the average. In an ideally homogeneous and isotropic medium, this phenomenon would be minimal, but not entirely eliminated. In a natural formation, dispersion, perhaps together with fingering, can play a determining role in limiting the utility of a site.

The movement of trace radioelements is dependent not only on the velocity of the transporting liquid, but also on the exchange capacity of the medium for the individual nuclides. Since ion exchange is not instantaneous, primarily due to the rate-limiting effects of diffusion, wide variations in the velocity of a single trace component are likely to occur. A complex interplay of physical and chemical parameters is thus seen to determine the manner in which a radioactive contaminant will move through the earth's crust.

The purpose of this paper is to outline quantitatively the basic relationships determining: (a) the extent of hydraulic dispersion, (b) the exchange capacities of several natural media for radiostrontium in the presence of such interfering cations as hydrogen, sodium, and calcium, and (c) the influence of rate-controlling steps in ion exchange contributing to variations in the velocity of strontium movement and limiting the useful storage capacity of an underground formation.

Hydraulic Dispersion in Porous Media

When one aqueous solution displaces another in a saturated porous medium, the boundary, or "front" between the two solutions becomes progressively more diffuse as the distance traveled increases. In the absence of ion exchange, the diffuseness is due almost entirely to microvariations in velocity within individual pores and from one pore to another. When cations in the displacing liquid enter into exchange reactions with the medium, these reactions may be expected to make an additional contribution to the diffuseness or depth of the front bounding the influent cations. This latter effect can, under certain circumstances, cause a far greater degree of dispersion than brought about by liquid velocity variations. Molecular diffusion is insignificant in comparison with dispersion resulting from liquid displacements. A quantitative description of dispersion is provided by breakthrough curves obtained by plotting the effluent concentration of a component as a function of time or effluent volume. The slope of the S-shaped breakthrough curve may serve as an index of dispersion.

Owing to the complexity of the flow channels in natural granular material, hydraulic dispersion in laminar flow is best analyzed by a semiempirical approach, assuming a random type of diffusion described by Fick's Law. Rifai *et al.* (1) has expressed this relationship by the differential equation

$$\frac{dc}{dt} = D\frac{d^2c}{dz^2} - S\frac{dc}{dz}$$

in which c is the component concentration, z the distance traveled, S the linear velocity and D the dispersion constant. In order to apply this equation to the analysis of saturated column systems, its solution may be used when expressed in terms of the throughput volume V, the pore volume vf, and the column length L.

$$\frac{c}{c_0} = \frac{1}{2}\left[1 - erf\frac{1 - \left(\frac{V}{vf}\right)}{2\sqrt{\left(\frac{D}{LS}\right)\left(\frac{V}{vf}\right)}}\right] \quad \ldots (1)$$

It is seen that Eq. 1 is a single-parameter family of curves relating the normalized effluent concentration, $\frac{c}{c_0}$, to the normalized throughput volume, $\frac{V}{vf}$. The parameter is the dimensionless group, $\frac{D}{LS}$.

Studies of Ottawa and Monterey sands by Rifai *et al.* (1) and of Oakley sand by Krone and Orlob (2), have shown approximately linear relationships between the dispersion constant D and the linear velocity S, *i.e.*, $D = D_mS$. This relationship stems from the fact that the shape of the breakthrough curve is nearly independent of the flow rate over a range of from 5×10^{-4} cm. per second to about 1 cm. per second in media having an effective size of approximately 0.45 mm. and a uniformity coefficient of 1.3. Eq. 1 may thus be rewritten as

$$\frac{c}{c_0} = \frac{1}{2}\left[1 - erf\frac{1 - \left(\frac{V}{vf}\right)}{2\sqrt{\left(\frac{D_m}{L}\right)\left(\frac{V}{vf}\right)}}\right] \quad \ldots (2)$$

A plot of Eq. 2 is shown in Figure 1, in which D_m is the medium dispersion constant and presumably dependent on such factors as effective size, uniformity coefficient, and particle shape. The validity of Eq. 2 has been demonstrated for column systems of relatively uniform grain size in which dispersion occurs only in the longitudinal direction. Field-scale studies of chloride dispersion in radial flow from an injection

well have provided breakthrough data that follow closely the curves shown in Figure 1. It is thus apparent that at least for the single-dimension case, the measurement of a single breakthrough curve on a column of known length permits the determination of the medium dispersion constant D_m. The breakthrough curves for longer columns of the same medium can then be selected from Figure 1. Such curves can be employed in estimating the maximum rate of travel of an inert component of an injected waste. Heterogeneities in the stratigraphy of a disposal site will of course place serious limitations on the reliability of this method. However, many of these uncertainties may be eliminated by the exploration of a formation with a harmless tracer prior to beginning waste injection.

Ion Exchange Phenomena

The theories of ion exchange in flow processes, as developed by Thomas (3) (4), and adapted to chemical engineering use by Hiester and Vermeulen (5), are based on differential equations describing material balances and kinetic relationships. Ion exchange capacity, equilibrium constants, and rate coefficients are generally assumed to be true constants representing the characteristics of a single homogeneous medium. The effects of hydraulic dispersion are not considered. The reasonably good agreement between the experimental results of numerous workers and these theories can probably be attributed to the fact that high-capacity resins were employed so that hydraulic dispersion became a negligible quantity. Furthermore, some degree of empiricism is inherent in mathematical expressions of such complex phenomena as ion exchange in columns.

Hiester and Vermeulen (5) have prepared several families of generalized breakthrough curves with which experimental data may be compared and from which certain parameters characterizing the reaction kinetics may be derived. One of these families, corresponding to the breakthrough of a trace component, is shown in Figure 2. For this condition, the equilibrium parameter r is equal to unity. This case is of special significance in the problem of radioisotope travel. When the waste component is present in an appreciable concentration, r as computed from Eq. 3 may no longer be unity and Figure 2 would not be applicable.

$$r_A = \frac{1}{1 + \frac{[K_A'' - 1](c_A)_0}{c_0}} \quad \ldots (3)$$

The term $(c_A)_0$ is the concentration of component A, and c_0 is the total concentration of exchangeable cations, in the influent. K_A'' is a modification of the mass-action constant, defined by Eq. 4.

$$K_A'' = \left[\left(\frac{c_B{}^a q_A{}^b}{c_A{}^b q_B{}^a}\right)\left(\frac{q_A + q_B}{c_A + c_B}\right)^{a-b}\right]^{\frac{2}{a+b}} \quad \ldots (4)$$

This expression (Eq. 4) corresponds to the replacement of ion B by ion A as given by Eq. 5.

$$bA^{+a} + B_a \cdot \text{clay} \rightleftharpoons aB^{+b} + A_b \cdot \text{clay} \quad \ldots (5)$$

The term $(c_B{}^a \cdot q_A{}^b) \div (c_A{}^b \cdot q_B{}^a)$ in Eq. 4 is the mass-action constant in which c_A and c_B are the solute concentrations in milliequivalents per liter and q_A and q_B are the equilibrium concentrations of A and B in the solid phase expressed in milliequivalents per gram. The valences of A and B are a and b, respectively. For symmetrical exchange, *i.e.*, $a = b$, K_A'' equals the mass-action constant.

The abscissa of Figure 2 is a dimensionless throughput parameter, as expressed by Eq. 6.

$$T_A = \frac{(c_A)_0(V - vf)}{(q_A)_\infty \rho_b v} \quad \ldots\ldots (6)$$

This is analogous to the normalized throughput volume, $\frac{V}{vf}$, used in the

analysis of hydraulic dispersion (Figure 1). The ultimate concentration that component A can reach in the solid phase is $(q_A)_\infty$, corresponding to a solute concentration of $(c_A)_0$ in the influent. The factors v and ρ_b correspond to the gross volume and the bulk density of the medium. Each curve is characterized by s, the "column capacity parameter" as defined by

$$s = k\left(\frac{vf}{R}\right) = k\left(\frac{L}{S}\right) \quad \ldots\ldots (7)$$

in which k is the general rate constant and R the volumetric flow rate. The column-capacity parameter is analogous to $\frac{D_m}{L}$ as previously discussed.

It may be well to discuss qualitatively the effect of certain factors on the configuration of the breakthrough curves. These factors may be considered in two categories: (a) those influencing the shape of the normalized breakthrough curves and (b) those entering into the definition of T by Eq. 6 and thus transforming the normalized plots into a direct relationship of V and $\frac{c}{c_0}$.

The factors governing the shape of the breakthrough curve are the equilibrium parameter r, the column capacity factor s, and whether external or internal diffusion is the rate-determining mechanism. The advancing front is sharpest at low values of r and high values of s. In the case of trace components, r is nearly equal to one. For the binary exchange of gross components, favorable equilibria, corresponding to values of the mass-action constant above unity, contribute to the sharpening of the breakthrough front. Large general-rate coefficients and small flow rates also serve to steepen the breakthrough curve (Eq. 7). A more detailed discussion of the general-rate coefficient is found in the literature (5)(6).

By referring to Eq. 6, it is noted that when $T = 1$, a volume of liquid V has entered the column, sufficient to fill the pore volume vf and containing an amount of component A equal to the ultimate exchange capacity $(q_A)_\infty \rho_b v$ for that component at concentration $(c_A)_0$. The volume corresponding to $T = 1$ may be termed the "average breakthrough volume" and can be computed from the expression $\bar{V}_A = vf + \frac{(q_A)_\infty \rho_b v}{(c_A)_0}$. Since $\frac{vf}{\bar{V}_A}$ equals the ratio of the average linear velocity F_A of component A to the average fluid velocity S, the expression becomes

$$\frac{F_A}{S} = \frac{1}{\left[1 + \frac{(q_A)_\infty \rho_b}{(c_A)_0 f}\right]} \quad \ldots\ldots (8)$$

For the simple case of a single cationic species displacing another, q_∞ is the total exchange capacity of the medium and the ratio $\frac{F}{S}$ is dependent almost entirely on the influent concentration, $\frac{\rho_b}{f}$ being essentially constant for natural media. In the more complex case of several exchanging cations, the capacity of the medium for a particular component $(q_A)_\infty$ will depend on $(c_A)_0$ and the equilibria existing between A, the gross components of the system, and the medium. As the column length is increased, the slope of the breakthrough curve becomes relatively less significant and the average velocity assumes greater importance.

Studies of Ion Exchange Equilibria

The purpose of the laboratory studies was to measure the parameters determining the average displacement and dispersion of trace strontium fronts in their passage through natural porous media. The three most important parameters have been shown to be: (a) the exchange capacity, (b) the equilibrium constant, and (c) the general rate coefficient. The materials studied included a California agricultural soil, several typical California oil sands, and an American Petroleum

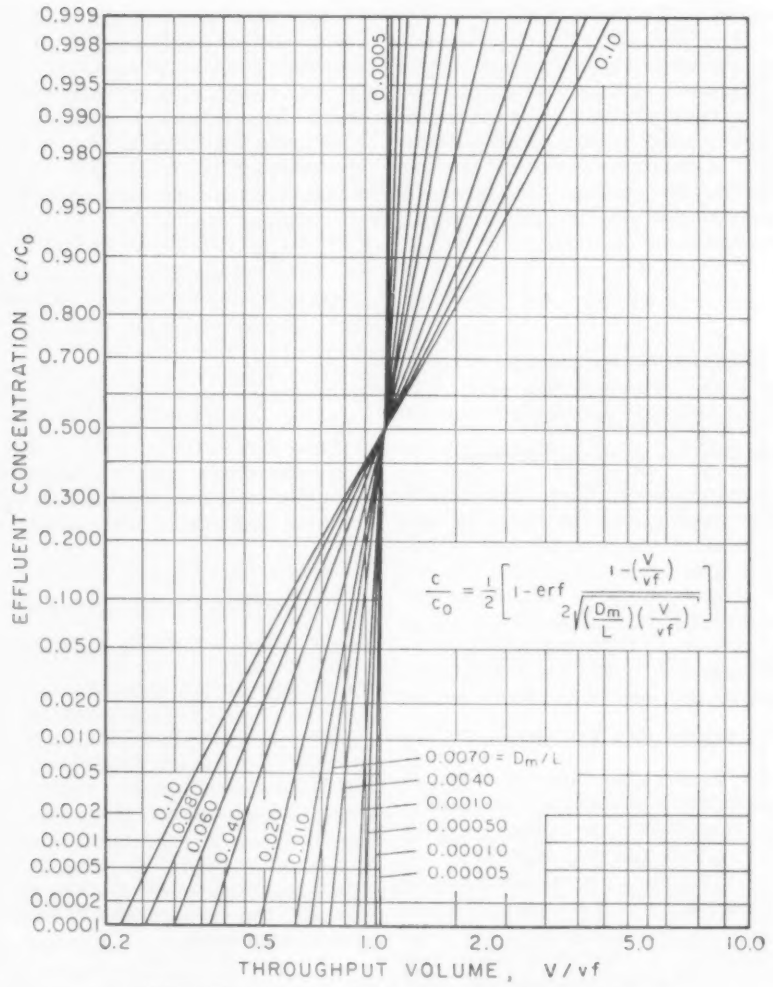

FIGURE 1.—Generalized hydraulic dispersion curves.

Institute standard halloysite clay. The first two materials were chosen as representative of deep connate-water bearing formations and surface soils. The solutions employed contained 1 p.p.m. of stable strontium and were otherwise relatively simple in composition. No attempt was made to simulate any particular radioactive waste.

Determination of Exchange Capacities

The studies were conducted with both column and batch systems, depending on the particular parameter under investigation. The columns had an inside diameter of 19 mm. and a length of 3.5 in., unless otherwise noted. They were generally presaturated with a known solution in order to simplify the interpretation of the breakthrough data. For example, when the exchange of calcium and strontium with sodium was examined, the columns were presaturated with a simulated connate brine (0.09N NaCl and 0.06N $NaHCO_3$).

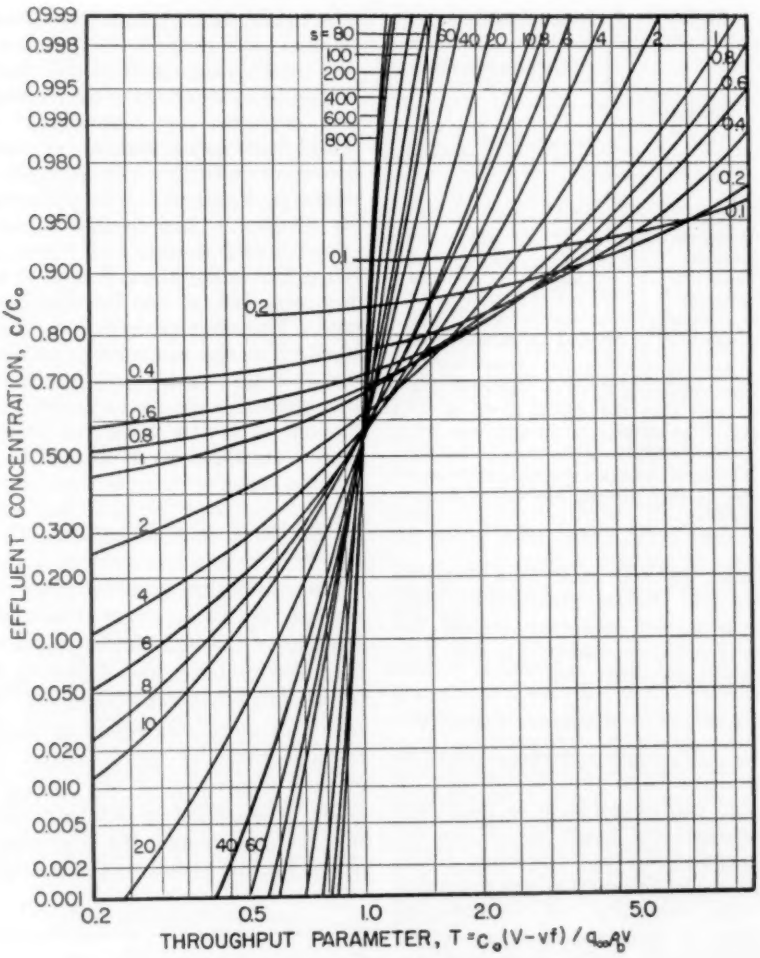

FIGURE 2.—Generalized breakthrough curves, $r = 1$.

Batch experiments were used to determine certain of the exchange capacity and equilibria data. The media were presaturated with successive portions of a solution of traced cations until no further uptake was indicated. The tracers were then removed by successive elutions with a solution chemically identical to the saturating solution but free of radioactive tracers. The exchange capacities and equilibrium constants were then computed from radioassay data and the known cation concentrations of the saturating solution. A summary of the exchange capacity determinations is given in Table I.

The measured exchange capacity is known to depend on the laboratory procedure employed. Therefore, a method was chosen to duplicate as nearly as possible the conditions expected in the field where the results are to be applied. To ascertain whether equilibrium was reached in the columns, it was considered desirable to determine the exchange capacity by both batch and column

TABLE I.—Exchange Capacities

Material	Exchange Capacities (meq./100 g.)		
	Column*	Batch*	Ammonium Acetate
Sands:			
Coalinga	0.3	—	0.2
Dominguez	5.7	5.6	5.6
Lost Hills†	13.0	—	14.1
Richfield	2.4	—	2.4
Rosecrans	4.7	4.3	4.3
Halloysite Clay†	14.9	8.7	10.8
Yolo Soil†	25.1	25.6	15.2

* The saturating solution was 0.1N Ca^{++} traced with Ca^{45} and 2.28×10^{-5}N Sr^{++} (1 p.p.m.). The effluent pH ranged from 7.3 to 7.7.

† Mixed with an equal weight of acid-washed asbestos (Gooch Grade, Merck) to improve permeability.

methods, as well as by the standard ammonuim acetate procedure. Fair agreement was observed among the various methods, except for the Yolo soil and halloysite.

Effect of pH on Exchange Capacity

Due to the wide pH range found in the wastes from the reprocessing of nuclear fuel elements, it is important to evaluate the effect of pH on ion exchange equilibria. The study of pH presented in this section was prompted by the necessity of determining whether a calcium-strontium system was essentially a two-component system or whether the omnipresent hydrogen ion seriously influenced the measured exchange capacities and equilibrium constants. It is appreciated that the limited data reported are adequate only to illustrate the general effect of the competing hydrogen ion on the quantities of sorbed calcium and strontium ions.

The halloysite clay and the Dominguez sand were selected for study. The procedure was identical to the batch technique described previously. Samples of the two media were brought into equilibrium with a traced 0.01N Ca and 2.28×10^{-5}N Sr solution at pH values ranging from 2.3 to 7.2. The sorbed cations were then removed and measured by radioassay. The equilibrium concentrations of sorbed strontium at various values of pH are shown in Figure 3. The corresponding change in the calcium exchange capacity ranged from 1 to 9 meq. per 100 g. for halloysite and from 3 to 6 meq. per 100 g. for the Dominguez sand. The effect on halloysite may be ascribed to the competitive action of the hydrogen ion. In the case of Dominguez sand, the dissolution of calcium carbonate from the medium caused an apparent reduction in the calcium capacity.

Measurement of Equilibrium Constants

The equilibrium constant determines not only the average rate of movement of a cation through porous media, but may also influence the degree of dispersion of the concentration front. Unfavorable equilibria result in greater average rates of waste travel and greater dispersion of the advancing front. The laboratory studies reported in this section include the measurement of equilibrium constants for strontium

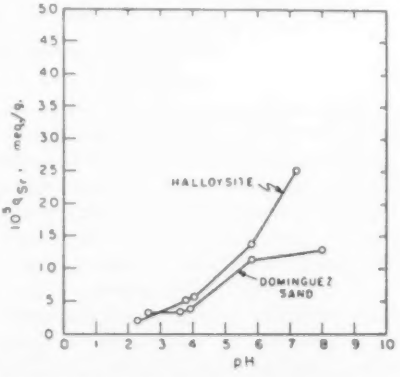

FIGURE 3.—Effect of pH on partial exchange capacity for strontium.

replacing calcium (K''_{Sr-Ca}) and calcium replacing sodium (K''_{Ca-Na}). In addition, the influence of sodium and hydrogen ion on the strontium-calcium equilibrium has been considered.

For the measurement of K''_{Sr-Ca} (Eq. 4), parallel column and batch systems were saturated with a solution containing 0.01N Ca and 2.28×10^{-5}N Sr traced with Ca^{45} and Sr^{89}. The tracers were then eluted and the quantities of sorbed calcium and strontium determined by radioassay. Data for calcium (q_{Ca}) are those reported as exchange capacities in Table I. Values of K''_{Sr-Ca} are presented in Table II. It was also possible to obtain q_{Ca} and q_{Sr} during the saturation step of the column experiments.

The comparative constancy of the K'' values obtained for materials as different as the sands, a relatively pure clay, and the agricultural soil, is of particular interest. Although the exchange capacities of natural materials may vary over wide limits, the relative affinities of these materials for strontium and calcium appear to remain nearly constant. Laboratory studies currently in progress indicate that equilibrium conditions are reached very slowly in certain media and suggest a possible source of error in the constants shown in Table II. However, the batch data agree fairly well with the column studies, serving to support the accuracy of the data reported at this time.

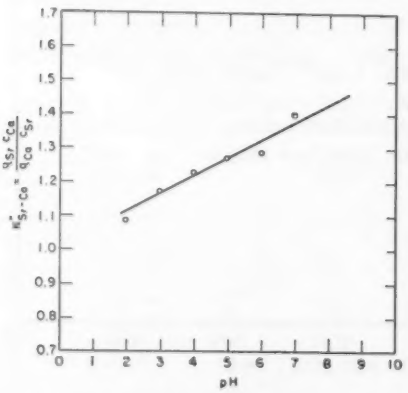

FIGURE 4.—Effect of pH on K''_{Sr-Ca}, halloysite.

TABLE II.—Strontium-Calcium Equilibrium Constants

Material	$K'' = \frac{c_{Ca} q_{Sr}}{c_{Sr} q_{Ca}}$; $a = b = 2$		
	Column		Batch
	Saturation	Elution	Elution
Sands:			
Coalinga	—	1.61	—
Dominguez	1.29	0.98	1.15
Lost Hills*	1.53	1.40	—
Richfield	1.48	1.28	—
Rosecrans	1.28	1.26	1.23
Halloysite Clay*	1.68	1.34	1.31
Yolo Soil*	1.38	1.17	1.21

* Mixed with an equal weight of asbestos.

If the 0.98 value for Dominguez sand is excluded, it may be concluded that strontium is more favorably sorbed than calcium and that the strontium breakthrough curve for a calcium- or sodium-saturated medium should be comparatively steep. Both of these observations imply that natural media exchange preferentially with strontium and that a relatively efficient utilization of underground formations is possible.

The effect of pH on the strontium-calcium equilibrium constant is shown in Figure 4. These values were computed by Eq. 4 from data obtained in the experiment concerned with the influence of pH on exchange capacity. It is apparent that a reduction in pH effected a greater relative reduction in strontium than in calcium uptake. In a subsequent experiment, the presence of 0.09N sodium was observed to bring about an increase of the K''_{Sr-Ca} for Rosecrans sand from 1.3 to 1.8, an effect opposite from that observed with increasing hydrogen ion concentration.

Ion Exchange Kinetics in Natural Media

The influence of the ion exchange equilibrium constant and the column-capacity parameter was described in the section dealing with the kinetic theory. To illustrate the applicability of the kinetic theory to natural exchange media and the kinetic characteristics of various media, several column experiments were conducted on the material previously discussed. The influence of the equilibrium constant on the breakthrough curve is shown in Figure 5. In the case of the self-exchange of calcium ($r = K'' = 1$), the equilibrium was favorable and the breakthrough relatively sharp. In the case where 0.1N sodium displaced calcium, the equilibrium was unfavorable ($K''_{Na-Ca} = 0.19$) and a flat breakthrough resulted.

Influence of the Column-Capacity Parameter on Dispersion

The column-capacity parameter (Eq. 7) influences the degree of dispersion as shown in Figure 2; the larger s is the less the relative diffuseness of the advancing front. The general-rate coefficient k is dependent on the diffusivity of the exchange cations and the resistance of the medium. By passing a traced solution of 0.01N Ca and 2.28×10^{-5}N Sr through columns of the various media saturated with 0.09N Na, it was possible to obtain breakthrough curves for strontium and calcium. Although the equilibrium constants for calcium-sodium were not determined for each system, it may be inferred from the Rosecrans sand study that the equilibrium was favorable in each instance. In order to

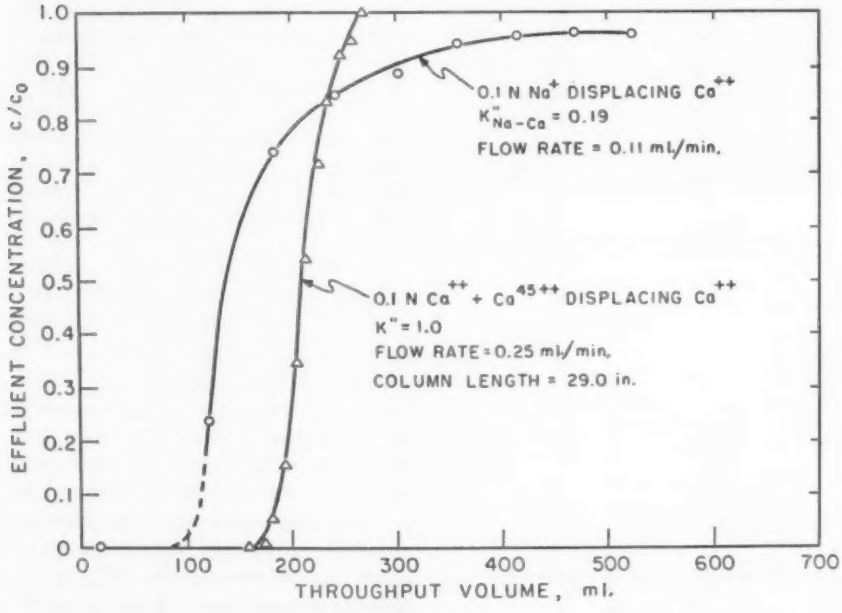

FIGURE 5.—Effect of equilibria on dispersion, Rosecrans sand.

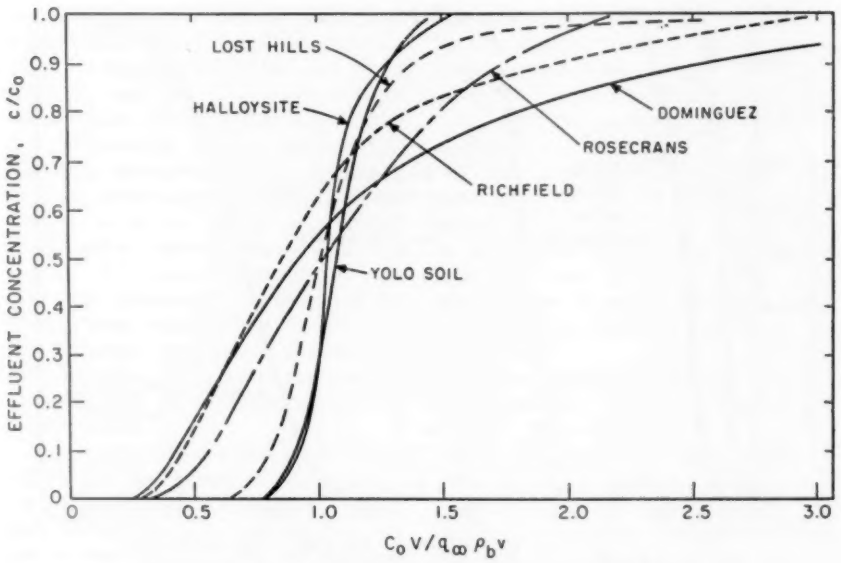

FIGURE 6.—Strontium breakthrough, normalized plots.

evaluate the contribution of hydraulic dispersion, chloride breakthrough curves were measured for each column. From these curves it was concluded that hydraulic effects were making only an insignificant contribution to front dispersion of the exchanging cations.

The breakthrough curves for strontium are shown in Figure 6. The throughput volume V was normalized to aid in comparing media of widely different exchange capacities. Pertinent data describing the conditions of each run are given in Table III. It is apparent that differences in the dispersion effect caused by various media must be attributed to rate phenomena and are dependent on particle size and mass-transfer coefficients. The configuration of the corresponding calcium breakthrough curves for each medium was quite similar, indicating a relative independence of the internal resistance of the ionic species diffusing into the exchange sites.

TABLE III.—Column Data—Strontium Breakthrough

Material	Weight, $\rho_b v$ (g.)	Voids, vf (ml.)	Flow Rate, R/a (ml./min./sq.cm.)	Average Breakthrough Volume, $\bar{V}_{Sr}$ (ml.)
Sands:				
Dominguez	37.3	13.7	0.023	294
Lost Hills	7.25	21.5	0.032	199
Richfield	42.6	14.4	0.050	158
Rosecrans*	27.5	12.0	0.040	180
Halloysite Clay	14.8	19.1	0.014	395
Yolo Soil	15.4	18.0	0.003	565

* Column length 3.0 in., all others 3.5 in. The pH ranged from 8 to 9.

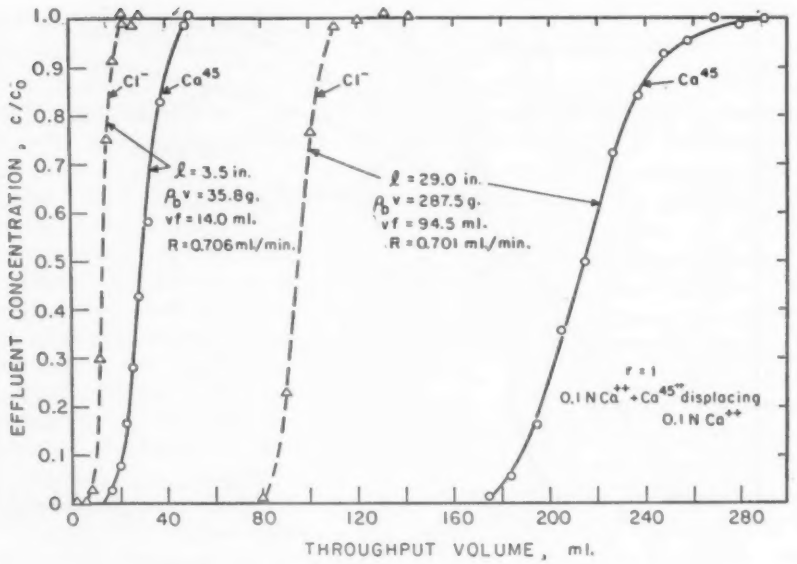

FIGURE 7.—Effect of column length, Rosecrans sand.

Effect of Column Length

The influence of column length or "travel distance" on the degree of dispersion of concentration fronts is of particular importance in the design of underground waste disposal systems. Since the general rate coefficient should remain independent of column length, it is possible to determine this factor on a short column and subsequently employ it to predict the breakthrough characteristics of a much larger system. The direct field application of this relationship is possible by the employment of a small-scale field study to aid in the design of the full-scale operation.

The independence of the general rate coefficient k from column length was studied for the self-exchange of calcium in Rosecrans sand. The results are shown in Figure 7. By comparing the Ca^{45} breakthrough curves for each column with Figure 2, the column-capacity parameters were estimated. From Eq. 7 the rate coefficients were then computed and found to equal 0.45 min.$^{-1}$ for each column, thus corroborating the theory that data from short columns may be extrapolated for use on long columns.

Summary and Conclusions

The feasibility of employing underground formations for the retention or permanent storage of radioactive wastes is dependent on: (a) the chemical and physical compatibility of the waste with the receiving formation and (b) the degree of certainty of predicting the velocity and direction taken by the more hazardous components of the waste.

The first criterion is met if the waste is free of particulates or chemicals forming precipitates when mixed with the soil and ground water. The second condition is the most critical from the standpoint of public health and public relations and admittedly will be extremely difficult if not impossible to meet under all circumstances. How-

ever, it is believed that the geology of many areas when examined together with the location of cities and water supplies, may offer a disposal resource about which the engineer may design a free-discharge ground disposal system with the assurance that the wastes will not subsequently constitute a hazard to health or in any way impair the beneficial uses of ground or surface waters. To enable the designer to provide such assurance, it is necessary for him to understand the hydraulic and ion exchange phenomena determining the direction and maximum rate of movement of trace concentrations of radioisotopes.

The several theories presented in this paper describe quantitatively hydraulic dispersion, ion exchange equilibria, and ion exchange kinetics as they apply to the movement of radioisotopes through natural porous media. Laboratory studies have been conducted with radio-strontium and several natural exchangers to determine the applicability and limitations of these theories. The laboratory results obviously do not conclusively establish that the maximum rate of strontium movement can be readily predicted under all circumstances. However, it is believed that the theories of dispersion and ion exchange, when used in conjunction with field-scale tests, will serve to reduce greatly the uncertainties of ground disposal operations. The salient experimental results are summarized as follows:

1. Hydraulic dispersion, or longitudinal mixing, in porous media can be treated mathematically as a random phenomenon analagous to molecular counter diffusion. A solution has been presented that closely depicts the breakthrough of non-exchanging hydraulic tracers. Dispersion, as measured by the slope of the breakthrough curve, was shown to be dependent on the medium and the distance traveled, but essentially independent of velocity. By considering hydraulic dispersion, it becomes possible to estimate the maximum rate of travel of those components of a waste not entering into exchange reactions with the medium.

2. The exchange capacities of connate sands of widely different origins ranged from 0.3 to 13.0 meq. per 100 g. as determined by the use of calcium ion traced with Ca^{45}. Generally, these results were in good agreement with those obtained by the ammonium acetate method.

3. The strontium-calcium equilibrium constants for the various media ranged from 0.98 to 1.68, averaging 1.33. Although the media examined were of widely different origins, the relative preference for strontium and calcium was nearly constant and, with one exception, favored strontium. A low pH value was observed to reduce both the exchange capacity for strontium and calcium and the strontium-calcium equilibrium constant. Sodium had a similar effect on the uptake of calcium and strontium. However, the calcium-sodium equilibrium constant was found to be 5.3, indicating a considerable preference for calcium and presumably strontium.

4. The diffuseness or dispersion of a cation front, as the result of exchange reactions, may be far greater than that attributable to hydraulic effects alone. Exchange reactions involving favorable equilibria, such as strontium replacing sodium or calcium, tend to produce relatively steep breakthrough curves, *i.e.*, little dispersion. However, the rate-limiting effects of film and particle diffusion, when coupled with appreciable flow velocities, cause a high degree of front dispersion. This phenomenon is of practical significance since it increases the maximum rate of waste travel in comparison to the average rate and serves to reduce the effective storage capacity of a formation.

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A HIGHLY ALKALINE pH STANDARD

To increase the accuracy of pH measurements in the highly alkaline range, the National Bureau of Standards is recommending a sixth pH standard for use along with the five pH standards previously established. Consisting of a saturated solution of calcium hydroxide, the new standard will provide an additional fixed point in the standard pH scale which the Bureau maintains.

This scale was set up in 1948 to meet the need for a single standard pH scale as a basis for accurate measurement of acidity and basicity in aqueous solutions. It is defined in terms of several fixed points in much the same manner as is the International Temperature Scale. The primary standards of the pH scale are solutions whose pH values are only slightly affected by dilution or by accidental contamination with traces of acid or alkali from the walls of the container or from the atmosphere. The substances from which the standard solution are prepared are, in turn, stable materials which may be obtained as certified standard samples from the Bureau. The five standards thus far established cover the pH range from 1.68 to 9.18 at 25° C. However, the need for a highly alkaline standard has been felt for several years.

The new pH standard is a solution of calcium hydroxide saturated at 25° C. This reference solution is easily prepared. No weighings are necessary, as a solution of reproducible composition can be made merely by shaking finely granular calcium hydroxide with water. The calcium hydroxide is prepared by igniting calcium carbonate conforming to American Chemical Society specifications for the reagent grade low in alkalies. The solid material must not be contaminated with soluble alkalies, but the presence of carbonate is of no concern, since calcium carbonate will precipitate from the solution at the time of preparation. The filtered solution of calcium hydroxide supersaturates readily and can normally be used over a wide range of temperatures without separation of the solid phase.

The pH of this solution is 12.45 at 25° C. and is a rather sensitive function of temperature. Values of pH on the NBS conventional activity pH scale have been assigned at intervals of 5° for 0° to 60° C. Although standard samples of calcium hydroxide are not yet available from the Bureau, highly pure preparations can readily be made from commercially available grades of calcium carbonate.

WATER CONSERVATION AND RECLAMATION SYSTEM FOR A COPPER WIRE MILL*

By G. W. Pirk

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The Rome Cable Corporation, located at Rome, N. Y., manufactures electric wires and cables. In common with many other wire mills having a hot rolling operation for rod production, it has been faced with the necessity of modernizing its operation for the dual purpose of reducing its requirement for city water and recovering and reclaiming copper which was previously lost in the plant effluent. The purpose of this paper is to describe the methods which were employed in this effort and the results which have been achieved.

Production of Rolled Copper Rod

It may be helpful at this point to offer a brief description of the method by which copper conductors are manufactured. Production is initiated in the rod mill. Here 4 in. by 4 in. by 54 in. cast copper wire bars, which weigh about 250 lb., are heated to 1,650° F. and then passed through a series of grooved rolls which, in a series of steps, gradually reduce them to round rod. The size of the rod rolled varies in diameter from 5/16 in. to 9/16 in., depending on the final size and shape of the copper conductor desired. During the rolling process, water under pressure is directed onto the grooved rolls for the purpose of keeping the roll grooves cool and reducing the adherence of scale to them. It also serves to blast copper scale from the hot copper rod, thus preventing it from being rolled into the hot rod which is very soft and plastic at the rolling temperature.

The water used to cool the grooves in the rolls that reduce the bar to round rod is generally either city water or water obtained from some other source, such as a river or canal. After its use for this purpose, it contains a substantial quantity of copper oxide which is well worth the effort of the manufacturer to recover. The earliest measure taken to reduce copper loss incidental to the hot rolling operation was the installation of a settling system. It is also, in terms of application and usage, the simplest and least expensive procedure to carry out. All that is required is the construction of a series of settling pits, through which the water passes on its way to final disposal. Most of the copper oxide (several hundred thousand pounds per year) settles in these and it is only necessary to clean the pits periodically to remove and recover the accumulated scale. However, the finer particles of copper oxide remain in suspension in the water as it leaves the pits and thus become a direct loss.

Problems at Rome Cable

Water Use

The Rome Cable Corp. is not situated so that the use of canal or river water would be either convenient or economical. Therefore, it has been necessary to use city water in large quantities for use on the rolls and for coil washing after pickling. Before water conservation practices were instituted, the rod mill consumed about 1,200,000 gal. per day when operating

* Presented at the 1957 Annual Meeting, New York Sewage and Industrial Wastes Assn.; New York, N. Y.; Jan. 17–18, 1957.

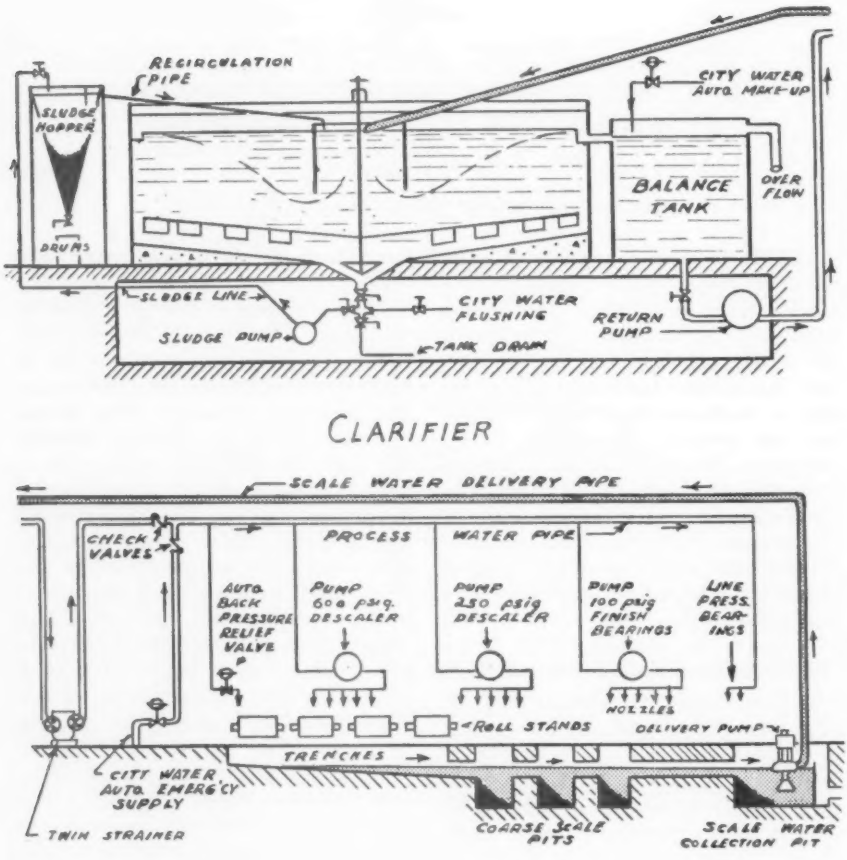

FIGURE 1.—Diagrammatic sketch of the layout for copper scale water reclamation system, Rome Cable Corp., Rome, N. Y.

at maximum capacity. This is about 10 per cent of the average daily consumption for the entire city of Rome. Since water conservation is a major problem in Rome, as it is in many other communities, it was clear that conservation measures should be put into effect at Rome Cable in the best interest of the community.

Copper Loss

After the water used on the rolls left the scale pits, it was formerly discharged directly into the New York State Barge Canal. Analyses showed that approximately 500 lb. of copper were being lost daily in the discarded scale water when the rod mill was operating at full capacity. This was a further indication that improvements in the method of handling this water were required.

Corrective Measures

Over a period of several years various methods of recovering the fine cop-

per oxide remaining in suspension in the scale water were investigated. As part of the project, an experimental settling tank was designed, constructed, and operated. In addition various other procedures, including filtering, were investigated. It was finally decided that settling was most suitable for the operation.

Thickener Operation

Figure 1 shows how the clarifier was integrated with the rod mill. The operation now became a closed recirculating system with the water being pumped onto the rolls, draining into the scale drop-out pits, and then through the clarifier back to the rod mill. A switch-over valve was installed in the line which automatically puts the system on city water should a failure develop which would interfere with or stop circulation in the system. Check valves are provided to prevent back-flow of the scale water into the city water system. The effluent from the clarifier flows into the balance tank and from there it is pumped back to the rod mill. This water (process-water pipe) is used at line pressure to lubricate the roll bearings. For the finishing roll bearings it is raised to 100 p.s.i.g. Auxiliary high-pressure pumps raise the water to 600 and 200 p.s.i.g. for use on the roughing and intermediate rolls and on the finishing rolls, respectively. City water is used to lubricate and cool all pump bearings.

Water Conservation

Prior to the installation of the clarifier for fine-scale recovery, the rod mill was using 114,000,000 gal. of water yearly. City water was used on the rolls at the rate of 1,300 g.p.m. The installation and use of the clarifier and the recirculating system has made it possible to use water on the rolls at an increased rate without actually consuming a greater amount. At present, pumping to the rolls is at the rate of about 1,700 g.p.m. of recirculated water compared to the former 1,300 g.p.m. of city water. The installation of the clarifier reduced the actual city water consumption to about 600,000 gal. per day, the amount being used for pump bearing cooling and lubrication, washing of the coils leaving the pickle tanks, and for cooling the sulfuric acid pickle solution.

Copper Recovery

The savings in water consumption are thus quite evident. However, before any appreciable returns could be realized in terms of recovered copper, the bottom of the thickener unit had to be covered with about 1½ in. of copper oxide before the rakes were fully effective. It was not surprising, therefore, that during the first four months of operation only about 795 lb. of copper were recovered. However, it became evident, both from the appearance of the recirculated water and from chemical analyses, that there was a high concentration of finely divided oxide remaining in suspension. This meant the system was not operating efficiently. In fact, during the next three months only about 9,000 lb. of copper were recovered from a possible 27,000 lb. From an operating standpoint also, high concentrations of suspended oxide and other extraneous material are undesirable since this leads to plugging of the high pressure nozzles on the roll grooves in the rod mill. Research was therefore undertaken to find means of promoting the settling of the suspended oxide and thus produce clarification of the recirculated water.

One proposed method for bringing about clarification of the scale water was to add copper sulfate and treat it to produce cupric hydroxide, a flocculant type of precipitate. The large particles of cupric hydroxide floc settle rapidly and, in settling, trap the suspended oxide and thus remove it. To apply the copper hydroxide floc treatment, however, meant there would be

an added cost for reagents, tanks, volumetric pumps, etc. This cost was sufficient to reduce materially the value of the recovered oxide and was, therefore, more a matter of academic interest than a solution of practical value.

Another solution, which was considered but not tried, was the application of a coagulation technique, using iron or aluminum salts such as aluminum sulfate, ferric chloride or sulfate, sodium aluminate, etc., followed by filtration. Aside from the economic disadvantage of further investment in filters and auxiliary equipment, such a procedure would result in a reclaimed copper oxide which would necessarily be contaminated with the coagulant used.

Some of the newer flocculating agents were also investigated but were decided against, partly for economic reasons and partly because of the fragile nature characteristic of flocs, which makes it possible to break them up and redisperse them, especially in a circulating solution.

In the Rome Cable laboratory, a number of approaches were tried. These included applying a D.C. voltage across the platinum electrodes on a conventional Fisher electro-analyzer. This treatment did precipitate the suspended oxide but was decided against because, if used on a plant scale, the cost would have been prohibitive. The addition of 1,200 p.p.m. of calcium sulfate to the recirculating scale water was also tried and it brought about coagulation of the suspended oxide. However, this procedure was, in effect, manufacturing hard water, with the possibility of getting lime deposits in the pipes, and was therefore abandoned.

The suspended oxide in the recirculated water was equivalent to 0.09 oz. of copper per gallon, or about eight times what it was when the scale water was wasted. This high concentration of oxide, in combination with extraneous materials, was plugging the nozzles in the rod mill and increasing bearing wear. At this point it was learned from some laboratory tests that if sufficient sodium hydroxide were added to increase the pH to between 9.5 and 10.5, almost immediate coagulation of the oxide particles occurred with extremely rapid settling. It was decided, therefore, to add 150 lb. of sodium hydroxide to the 114,000-gal. system. The results were dramatic. Copper analysis on the clarifier effluent showed that it had decreased to 0.0048 oz. of copper per gallon and the water was crystal clear. This same procedure has been maintained since, entirely by adjusting the pH by making daily additions of sodium hydroxide.

During the operating day, the water in the system is continuously recirculated, the clarifier rakes are kept in operation, and the sludge pump is operated at the rate of about 16 g.p.m. During the 14-hr. shut-down time, the system is quiescent, there being no recirculation.

The usefulness of the sodium hydroxide treatment is attested to by the fact that, in a 12-month operating period using the sodium hydroxide, approximately 100,000 lb. of copper have been recovered.

Discussion

The sodium hydroxide treatment is simple, inexpensive, and does not result in harmful contamination of the recovered copper oxide. Although the method has been in operation for only a year, there has thus far been no evidence of increased bearing wear on the rolls. In this time, no intensified corrosion problems or plugging of the water nozzles on the rolls has been noted. What plugging has occurred, seems to have been caused mainly by extraneous material that found its way into the system, *i.e.*, hair from the hair grease used in hot rolling, "Oil Dri,"

burlap fibers, etc. Strainers have been installed to overcome this. Nozzle plugging from oxide has not been bothersome and, when it has occurred, it has been localized in the smaller orifice nozzles near the end of the pipe lines where circulation is less than in the main part of the system. As a precautionary measure against any possible pipe plugging because of scale, the rod mill roll-pipe system is flushed at the end of the operating day for a few minutes.

After about a year of operation, there have been no significant expenditures for clarifier repairs and parts. The cost of the operation has been for such items as pumping the recirculated water through 2,200 ft. of pipe; daily labor to start and stop the unit; labor to remove sludge, load and ship the sludge to the refinery, and add sodium hydroxide; and, of course, the cost of the sodium hydroxide itself. In brief, the method adopted has performed as expected and has resulted in the anticipated savings.

Conclusion

The installation and operation of a system of water recirculation and copper reclamation has resulted in a twofold saving: first, a substantial water saving for the Rome Cable Corp. and for the community as a whole; and second, the recovery of about 100,000 lb. of copper annually which previously had been lost in waste.

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Stream Pollution

FACTORS AFFECTING THE RESPONSE OF FISH TO TOXIC MATERIALS

By Charles M. Weiss * and James L. Botts †

Biochemical Research Division, Chemical Warfare Laboratories, Army Chemical Center, Md.

The standardization of a bio-assay procedure requires an understanding of the variables and the degree to which they act in affecting the response of the biological material. In the use of fish for the study of water-soluble toxic materials, or in the evaluation by bio-assay of the toxicity of specific materials to fish, there will be physical and chemical factors of the aquatic environment, as well as physiological mechanisms of the living systems, that need be considered as influencing factors.

In recent years there have been several reports and papers (1)(2)(3)(4)(5) which have attempted to establish criteria for the use of fish in the bio-assay of toxic materials or in the evaluation of industrial wastes as a hazard to aquatic life. These studies have considered such factors as size, acclimatization, water source, temperature, dissolved oxygen, and number of animals per test container. However, in most cases these variables have been examined in light of establishing values which should be adhered to (or not exceeded) at certain limits, without indicating what can be expected if these criteria are exceeded or even allowed to fluctuate within the established limits. The response of the organism, outside of the standard value or limit, is particularly significant in establishing toxic tolerance limits for aquatic life since seasonal or other causes for changes in the physical and chemical characteristics of the environment can produce marked differences in tolerance levels.

That certain environmental factors might affect the response of organisms to toxic materials was observed by Sumner and Wells (6), who noted that the resistance of fish to poisons was affected by the difference in temperature of the water in which they had been living and the water in which they were tested. Southgate, Pentelow and Bassindale (7) and Downing (8) noted the very important effect of the amount of dissolved oxygen in the test fluid on the "resistance" of the fish to cyanide. This was true regardless of whether the fish were tested in still or continuous-flow systems.

In this paper an attempt will be made to evaluate the significance of several environmental variables as factors in controlling the response of fish to toxic materials as well as on the oxygen consumption of the fish. These variables are: (a) the period of acclimatization in the laboratory; (b) the dissolved oxygen content of the water in the test aquaria; (c) the size of the individuals of the species; and (d) the difference in acclimatization temperature and test temperature on oxygen consumption rate. This last variable is of particular significance

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with respect to toxic exposures, since the oxygen consumption rate is a possible measure of the rate at which many toxic materials may be absorbed through the gill membranes.

Methods and Materials

Three species of fresh-water fish, obtained from nearby hatcheries, were used in these experiments, but not necessarily all three in each experiment. The fish were the fathead minnow, *Pimephales promelas*, the green sunfish, *Lepomis cyanellus*, and the goldfish, *Carassius auratus*.

The test vessels were 12 in. by 12 in. round glass aquaria calibrated to 15 l. These aquaria were immersed in a large constant-temperature tank capable of maintaining the temperature of the vessels at $\pm 0.1°$ C. (9). All experiments were carried out at 24° C. unless otherwise noted.

The water used in these tests was the tap water of the Army Chemical Center, dechlorinated by passage through a carbon filter. The water is treated by coagulation, filtration, and chlorination with the final pH adjusted to 7.5. It is a soft water with a total alkalinity of 10 to 15 p.p.m.

The toxic material employed in these experiments was isopropyl methylphosphonofluoridate (Sarin). Weighed portions were suitably diluted with water and added to the 15-l. aquaria to prepare the desired concentrations. On the tests lasting several hours, the pH of the aquarium water was adjusted to 6.5 with 1M KH_2PO_4 to minimize hydrolysis of the Sarin.

The time for 50 per cent of the fish to respond (T50) was determined by introducing 10 fish in each aquarium under the particular experimental conditions and noting at a fixed time interval the cumulative number dying. The time interval was selected so that the number responding increased at each observation time by one or two individuals. When all fish had responded, the percentage response at each observation time was plotted on logarithmic probability paper and the T50 determined from a curve of visual best fit.

Oxygen consumption determinations were made by measurement of the dissolved oxygen content of the water in the test vessel on introduction of the fish and at the end of 2 hr. The toxic concentrations normally employed were such that the time for the first fish to respond was longer than 2 hr. and therefore did not interfere with the oxygen consumption determinations. After death of the fish, the drained wet weight of the 10 fish was obtained and their average weight used to calculate the oxygen consumption per gram of fish. There was no measurable effect of the Sarin on the oxygen consumption of the fish prior to their responding to the toxic effects. The 2-hr. respiration period permitted measurable differences in oxygen levels even under cold water conditions.

Although the use of an open respirometer is subject to criticism, the values obtained indicated that the degree of gas transfer across the water-air interface had a negligible effect during the course of these experiments and would be nearly constant for all determinations. The effects of gas transfer were minimized by keeping plastic covers on the aquaria which prevented air circulation across the top of the water. The movement of the fish kept the water adequately stirred. The water samples for oxygen determination were taken by siphoning from the mid-depth of the aquaria into 125-ml. bottles. The dissolved oxygen content was determined by the standard Winkler method. Concentrations of dissolved oxygen, at less than saturation, were obtained by scrubbing the water with nitrogen.

Results

Size

In a series of experiments, fish of varying sizes of the three species were

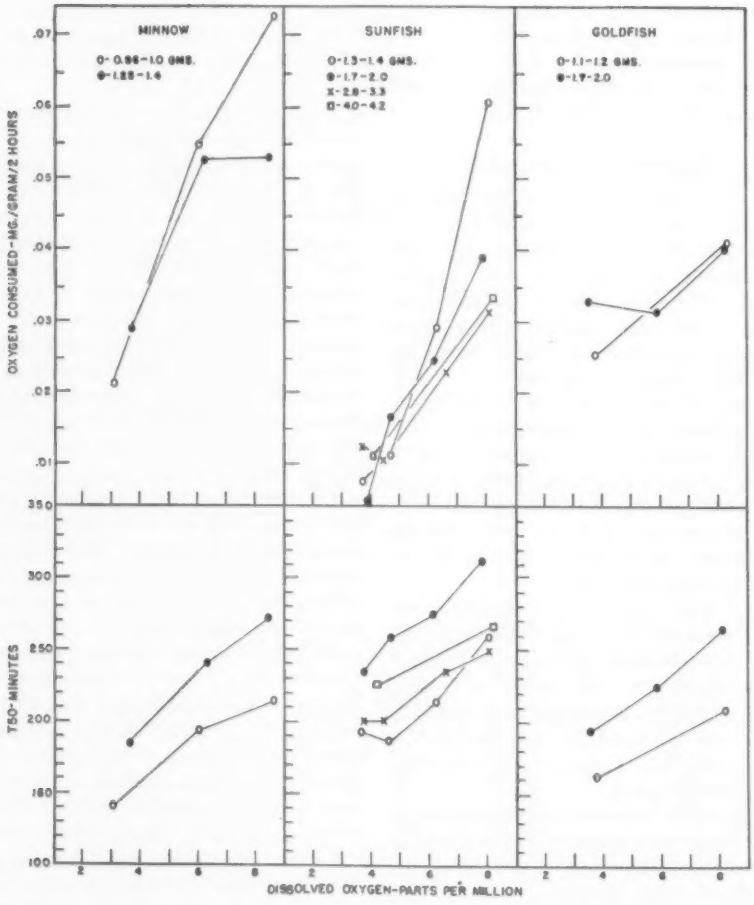

FIGURE 1.—The effect of dissolved oxygen concentrations on the response of minnows, sunfish, and goldfish to Sarin and on their oxygen consumption rates. The minnows and sunfish were exposed at concentrations of 12 p.p.b. and the goldfish at 40 p.p.b.

exposed to Sarin in water of different oxygen concentrations. As shown in Figure 1, for the three species and each sumption increased with increasing levels of dissolved oxygen in the aquaria. This behavior is similar to the response of rainbow trout to cyanide that Downing (8) observed. The size factor, as related to time of response and oxygen consumption, is fairly well described for the minnows; the large fish respond more slowly to the same dose and at the same dissolved oxygen levels. At the higher levels of dissolved oxygen, the smaller minnows have a higher oxygen consumption rate than the larger but are about the same at the lower dissolved-oxygen levels. The goldfish demonstrated a size differential in their response to the toxic material but the differences in oxygen consumption are not as well described. This may be due in part to the relatively small difference between the two sizes.

Sunfish exposed to Sarin at different

dissolved oxygen concentrations showed a similar increase in T50 and oxygen consumption, paralleling the rise in the dissolved-oxygen level. However, the size factor is not strictly proportional among the four size groups in their T50 response in this particular experiment. No reasonable statement can be made at present to explain why the smallest and next largest size groups (1.3 to 1.4 g. and 1.7 to 2.0 g.) showed the upper and lower limits of T50 response and the two larger groups (2.8 to 3.3 g. and 4.0 to 4.2 g.) responded at intermediate times.

The effect of size on oxygen consumption in the sunfish is presented again in Figure 2, over a wider range of sizes. Here the proportionalities are better defined. At oxygen saturation levels, at 24° C., between a weight of about 1.0 g. to nearly 6.0 g., the T50 increased by a factor of 1.6. The oxygen consumption rate, in turn, decreased by a factor of 1.57. These particular sunfish had been laboratory-acclimatized for 13 days, a factor which will be considered in the size-response-time relationship.

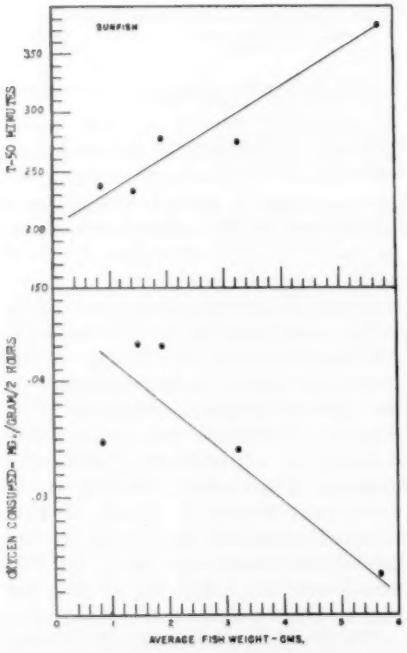

FIGURE 2.—The effect of size of sunfish on time of response to Sarin (10 p.p.b.) and oxygen consumption.

Time-Acclimatization

In Figure 3, the changes in dose-response-time and oxygen consumption of a batch of sunfish are plotted over a period of three weeks. On being received from the hatchery, the sunfish were sorted into the various sizes shown and kept in separate stock tanks until used. The first determination of

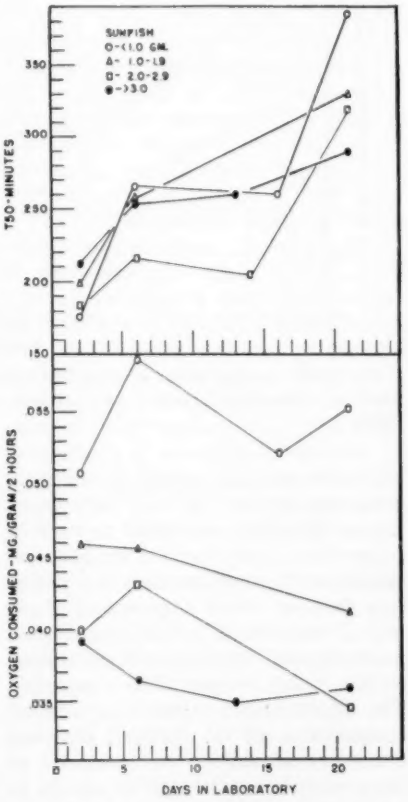

FIGURE 3.—The effect of time in laboratory stock tanks on the time of response of sunfish to Sarin (10 p.p.b.) and oxygen consumption.

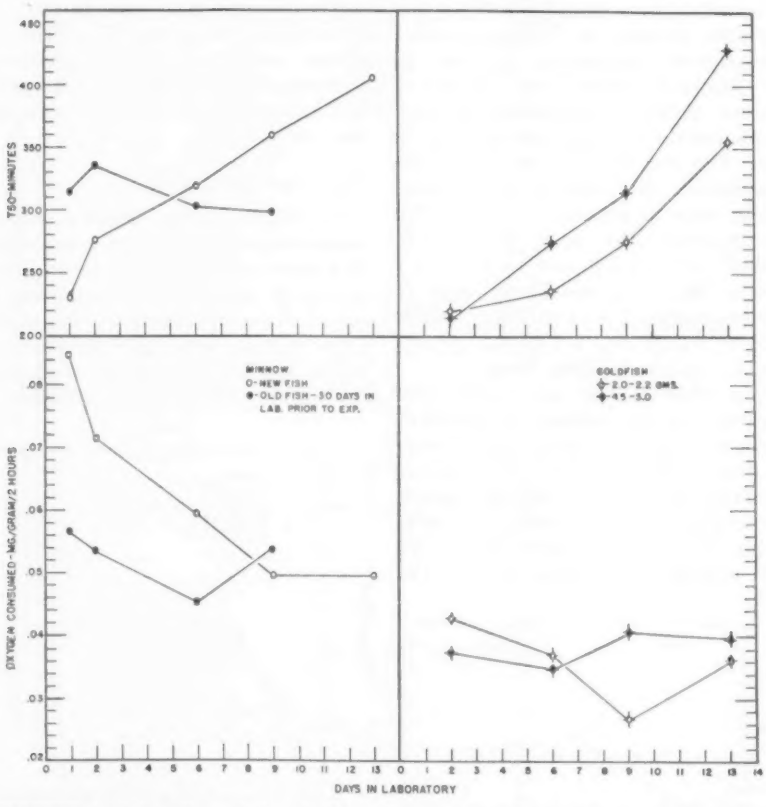

FIGURE 4.—The effect of time in laboratory stock tanks on the time of response to Sarin of minnows (10 p.p.b.) and goldfish (30 p.p.b.) and on their oxygen consumption rates.

T50 and oxygen consumption was made following 18 hr. in the laboratory tanks. The T50 was found to vary in proportion to size and the oxygen concentration to vary inversely in proportion to size. Over a period of three weeks, the T50 of all sizes increased markedly and the oxygen consumption of the three largest sizes decreased. The slight trend upward in oxygen consumption of the smallest size was somewhat anomalous as compared to other experiments of similar nature in which the small sunfish usually show the most marked downward change in oxygen consumption. Table I illustrates the order of change in these two components over the three-week period.

The change in the size-T50-response relationship over the 21-day period shown in Figure 3, and compared to the size-T50-response relationship of Figure 2, illustrates well the problems confronting attempts to standardize bio-assay procedures. The fish of the experiment shown in Figure 2 were received about 45 days prior to the fish of the experiment shown in Figure 3 and the difference in response may be some unknown seasonal factor.

The problem of laboratory acclimatization was also examined with respect to the minnow and goldfish (Figure 4). With the minnow a comparison was

made between fish which had been in the laboratory for 30 days and newly received fish. The old minnows showed little change in both T50 and oxygen consumption over a period of 9 days as compared to the new minnows. The latter demonstrate the usual increase in T50 and decrease in oxygen consumption.

Using the goldfish in a small-and-large-size comparison of the same laboratory age showed initial T50's that were practically the same for both sizes, but thereafter the larger specimens consistently had a greater T50 than the smaller. The change in oxygen consumption showed no apparent trend for the larger fish and a slight downward change in oxygen consumption for the smaller. In other experiments of this nature, the decrease in oxygen consumption with acclimatization time in the laboratory was more pronounced and paralleled the pattern of change seen in the sunfish and minnow.

Temperature—Oxygen Consumption

The problem of acclimatization in the laboratory to various experimental temperatures was examined with respect to the changes in oxygen consumption rates that followed when the fish were acclimatized or subjected to various temperature changes. This problem had been studied by Sumner and Wells (6) and Wells (10) with respect to acclimatizing fish at high and low temperatures and then examining their respiratory rate or response to anesthetics or toxic agents at some intermediate temperature.

In the experiments reported earlier in this paper, the relationship of changes in oxygen consumption and changes in response to toxics has been established. In the following studies only oxygen consumption values for various combinations of acclimatization temperature and respiration temperature were determined. The fish were acclimatized for 16 to 18 hr. prior to any particular determination of oxygen consumed. In each case the respiration period was 2 hr. Ten fish were placed in each 15-l. aquarium. Two sets of each size or species were run in duplicate at each temperature and the results averaged. The oxygen consumption values for the various experimental conditions are presented in Table II.

TABLE I.—The Magnitude and Order of Change in T50 and Oxygen Consumption of Sunfish Over a Three-Week Period *

Fish Size (g.)	Change in T50	Change in Oxygen Consumption
<1.0	+2.8	+1.1
1–1.9	+1.6	−1.1
2–2.9	+1.8	−1.2
3.0†	+1.4	−1.1

* Comparison of values on the first and last days of the series. All exposed at concentrations of 10 p.p.b. of Sarin.

† 3.0 g. and larger.

The results compare small and large sunfish and minnows. It is of interest to note that the small sunfish have oxygen consumption rates that are consistently greater than the large sunfish with the difference becoming smaller at the lower temperatures. Both sizes show oxygen consumption rates that increase with temperature. This same comparison of changing differences in oxygen consumption rates between different sizes in the same species was made for *Fundulus parvipinnis* by Wells (10).

The greatest change in rate of oxygen consumption occurred between 17° C. and 24° C. for each size or species. The oxygen consumption rates, as determined at temperatures for which the fish are acclimatized, are shown in Figure 5. When acclimatized at a temperature higher than the one at which the oxygen consumption rate is measured, the oxygen consumption values for both sizes of sunfish are always lower than the values when determined at an acclimatized tempera-

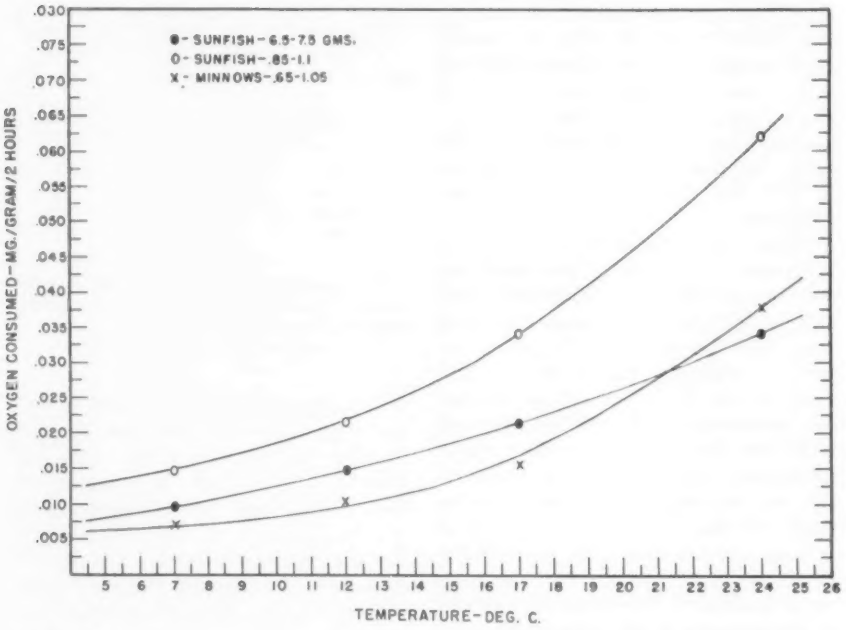

FIGURE 5.—The oxygen consumption rates of sunfish and minnows when acclimatized to several temperatures.

ture. This reduction in oxygen-consumption rate was dramatically emphasized when sunfish were transferred from water of 24° C. to water of 7° C. The fish go into a state of shock, cease respiring and die if not removed. However, when transferred from 17° C. water to 7° C. water this condition does not occur.

It is of interest to note for both sizes of sunfish that, when the fish are transferred from 24° C. and 17° C. water to 12° C. water, their oxygen consumption rates are nearly identical within the size but, of course, less than the rate when measured at a temperature for which they are acclimatized. This same pattern of change also is seen in rates determined at 7° C. when the sunfish are transferred from 17° C. and 12° C. water.

In contrast to the decrease in oxygen consumption rates of the sunfish when placed unacclimatized in colder water, the minnows have markedly higher rates than those fish which have been acclimatized to the specific temperature. Paralleling this behavior it was possible to transfer minnows from 24° C. water to 7° C. water with no outward evidence of harm.

Discussion

The consistency of the response of a species of fish to toxic materials can be influenced by many factors. Of the several that have been reported in the literature and this study, those that are most significant with respect to causing major differences in response time would seem to be: (a) temperature of the test water, (b) temperature acclimatization, (c) age acclimatization, (d) oxygen concentration of the

water, and (e) size of the fish. In each case these factors are demonstrably related to the oxygen consumption rate of the particular species.

In general, the oxygen consumption rate of the fish studied showed an inverse relationship to toxic response. A decrease in oxygen consumption paralleled increases in time of response to identical toxic concentrations. The decrease in time of response at low oxygen levels in test aquaria is explained by the compensating factor of increased ventilation rate to satisfy oxygen requirements even though the oxygen consumption rate may have been lowered when the fish were introduced to water with low-oxygen tension.

TABLE II.—Oxygen Consumption of Sunfish and Minnows, Acclimatized and Nonacclimatized, to Various Water Temperatures

Respiration Temperature (° C.)	Oxygen Consumption (g./2hr.) Acclimatization Temperature			
	24° C.	17° C.	12° C.	7° C.
(*a*) Small Sunfish (0.85 to 1.10 g.)				
24	0.0606	—	—	—
17	0.0235	0.0341	—	—
12	0.0143	0.0146	0.0215	—
7	*	0.0106	0.0100	0.0153
(*b*) Large Sunfish (6.50 to 7.50 g.)				
24	0.0344	—	—	—
17	0.0195	0.0211	—	—
12	0.0086	0.0083	0.0148	—
7	*	0.0042	0.0051	0.0095
(*c*) Minnow (0.65 to 1.0 g.)				
24	0.0379	—	—	—
17	0.0231	0.0153	—	—
12	0.0177	†	0.0097	—
7	0.0121	†	†	0.0069

* Values not determined because fish died.
† No experiment run at these conditions.

Conclusions

1. Changes in time of response to Sarin in a water solution have been shown to decrease relative to decreases in dissolved oxygen content of the water in the test vessel. Paralleling this change is a similar decrease in oxygen consumption rate. However, this contradiction is explained by an increase in ventilation rate to supply oxygen requirements at the lower oxygen tensions.

2. At oxygen saturation levels, changes in time of response due to laboratory acclimatization are inversely related to changes in the oxygen consumption.

3. Temperature acclimatization prior to a test exposure is necessary to allow for adjustment of the oxygen consumption rate.

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THE OPERATOR'S CORNER

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RESPONSIBILITIES OF A SEWAGE TREATMENT PLANT OPERATOR

BY DONALD M. PIERCE

Chief, Section of Sewerage and Sewage Treatment, Division of Engineering, Michigan Department of Health, Lansing, Mich.

Broad Aspects

Each of us is responsible for many things to many people in many ways. To live with others in even the simplest form of society requires the assumption of some responsibility—often automatically. An aborigine taking part in a tribal dance or group hunt for food assumes responsibility. Much the same kind of responsibility is accepted and discharged by the guard on a local high school basketball team or the fullback on a football team. Each belongs to a team and is an important part of it. Each is answerable and accountable to the team and to the group to which the team belongs. The rewards of successful performance and the burden of defeat, are shared by each member of the team.

Responsibility implies a relation between one who performs a task or duty or who executes a trust and the person imposing the task or duty. Such a relationship may exist between a husband and wife, between a depositor and his banker, or between an employee and his employer. Inherent in such a relationship is an understanding by both parties of the obligation and the conditions under which it is to be executed. More often than not, execution of the task or duty requires dependence upon others for assistance in some form. This is true, regardless of the kind, extent, or degree of difficulty or complexity of the responsibility.

Responsibility, to be effectively discharged, must be accepted willingly—not grudgingly. The nature of the task or duty should be examined carefully before the responsibility is accepted.

Responsible to Whom

As in most public service positions, the superintendent of a sewage treatment plant is responsible to one or more public officials and to the public at large. As the person in responsible charge of the plant, he frequently is required to submit operation reports directly to the state health department. Also, he may receive instructions from the field engineers and chemists. Of particular importance are the superintendent's responsibilities to members of his own staff at the treatment plant.

He is accountable to each group in a different way. It may seem sometimes that these several responsibilities are utterly incompatible. Sometimes they are. One of his greatest responsibilities is to make them compatible and properly serve the needs of each group.

Obviously, the specific duties and re-

sponsibilities of each position differ from those of any other position, however similar they may seem to be. The requirements and objectives for the job vary according to the size of the plant, the complexity of the equipment and process, the nature and use of the waters receiving the plant effluent, the attitude of the community and many other equally important considerations. Yet in many respects the same broad considerations prevail. Broadly speaking, each plant superintendent should be responsible for:

1. Effecting efficient continuous operation of the plant within the limitations of the facilities.
2. Maintaining plant records adequate for all reasonable purposes.
3. Providing responsible officials with information essential to planning, budgeting, and management of the plant.
4. Fostering good working conditions and incentives for subordinate employees.
5. Establishing and maintaining good public relations.

Effective discharge of these responsibilities requires teamwork among all who are associated directly with the management of the treatment plant. The superintendent is the captain of the team at the plant; but he is also a member of another team whose captain may be the city manager or other local official. Other members of this team may be the water superintendent, street superintendent, city engineer and other department heads. The treatment plant superintendent has the responsibility of keeping the city management informed of his needs and accomplishments, and how his program fits in with the other programs. He is the professional from whom the other members of the management team expect the answers—all of the answers—about the treatment plant. It is up to the plant superintendent to develop a knowledge and understanding of all of the elements of the operation so that he can provide the answers.

Changing Responsibilities

During the construction and break-in periods of a new treatment plant, the superintendent must become familiar with each element of the design and construction and with each piece of equipment. He should make specific recommendations to the responsible officials for correction of deficiencies and for justifiable improvements. When appropriate, he should help the designing engineer to understand more fully some of the operational aspects which affect the design. During this same period, the superintendent must develop a training program for members of his new staff so that they will be properly indoctrinated in performing the minimum essential operations when the plant is placed in service. Establishment of sound employee relationships during this period is very important. Employee schedules and personnel assignments must be developed before the plant is placed in operation.

During this early period it is important for the superintendent to make his needs and accomplishments known to his superiors. Concurrently, the plant superintendent must understand the character of the sewage. Particular attention must be given to industrial wastes which may have a deleterious effect upon plant structures, facilities, or processes. When such wastes are found, the superintendent should advise the appropriate city official and cooperate with him and with the responsible industry to develop a satisfactory method of treatment.

After the treatment plant has been in operation for several months, procedures and methods should become reasonably well stabilized. The superintendent should have more time to devote to management of the facilities. He should acquire a thorough knowledge of the plant, the sewage treated,

and the effects of the effluent on the receiving stream. He should keep informed about improved operating and maintenance practices.

Members of the plant staff should be encouraged to acquire the information they need to do their job effectively and to be prepared for increasing responsibility. The superintendent is responsible for effective and economical operation commensurate with the facilities and the attainable objectives. His records should accurately reflect these results, and they should provide a basis for decision on replacement of parts and for future enlargements or alterations to the plant.

The plant superintendent should always strive to anticipate needs for increased expenditures. He should be prepared at all times to give a clear understandable account of his needs and of the condition of the plant. The proper official should be advised of the needs in sufficient time to permit early planning and budgeting. As the maximum capacity of the plant is approached and the plant facilities depreciate, the needs for enlargement or replacement should be anticipated.

Public Relations

There are other responsibilities equally important. However, none is more important than the maintenance of good public relations. Pride of achievement and the knowledge of the importance of the operations can serve as a sound starting point. High morale and sense of responsibility among the plant staff are essential. A cordial and stable relationship between the responsible official and the plant superintendent is essential for effective public relations. The coordinated efforts of the total team at the plant are necessary.

A SYSTEM FOR THE QUALITATIVE ANALYSIS OF SEWAGE GREASES

By G. P. Gribkoff * and S. J. Nakada

Associate and Assistant Public Health Chemist, respectively, Branch Public Health Laboratory, Division of Laboratories, California State Department of Public Health, Los Angeles, Calif.

Grease is defined as "that material which is extracted from an acidified sample by petroleum ether," B.P. 35° to 54° C. (1). In most instances the quantitative determination as defined is adequate. However, in order to determine if grease samples submitted for analysis are of the same composition as grease from a typical sewage treatment plant, it is necessary to further analyze the grease for (a) the saponifiable fraction and (b) the nonsaponifiable fraction. The saponifiable fraction can be further analyzed for free fatty acids, soaps, and animal and vegetable fats and oils, as these components constitute the main saponifiable fractions of the acid-extracted grease in sewage. The nonsaponifiable fraction is not analyzed further because of the small percentage in the sample.

While existing and well established methods for determining the various fractions of oils and fats are available in the literature (2)(3), a method is not readily available to sewage plant chemists who do not have access to extensive literature references. In a brief search of the literature pertaining to sewage and industrial wastes, no ready system of analyses was found.

It must be kept in mind that the chemistry of the natural fats and oils

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is a subject of considerable complexity. Accordingly, the following definitions and equations are presented as they pertain to terms used in this paper. No attempt is made to cover the subject of fats and oils as given in text books.

Definitions

Saponifiable fraction—that fraction of the neutral extracted grease that will react with alcoholic KOH. Included are the free fatty acids and vegetable and animal fats and oils (3). Also included is soap, after the neutral extract has been acidified and extracted again with petroleum ether.

Free fatty acids—those compounds that are titrated immediately with 0.10N NaOH to a phenolphthalein end point. The free fatty acid is calculated, using 282 as a molecular weight, and reported as oleic acid.

Soap—the fraction that is extracted with petroleum ether after acidification of the neutral petroleum ether extracted residue (2).

Neutral fats and oils—the triglycerides of the fatty acids—see Eq. 2.

Nonsaponifiable fraction—the extracted grease that does not react with alcoholic KOH. Included are the hydrocarbons and mineral oils, as well as waxes, sterols, and other materials (4).

Equations

Titration of Free Fatty Acids

$$CH_3\text{-}(CH_2)_{16}\text{-}COOH + NaOH \rightarrow CH_3(CH_2)_{16}\text{-}ONa + H_2O \quad \ldots\ldots (1)$$

Fatty Acid → Soap + Water

Saponification of Fats and Oils

$$\begin{array}{l} CH_2O\text{-}C(=O)\text{-}R^* \\ | \\ CHO\text{-}C(=O)\text{-}R^* \\ | \\ CH_2O\text{-}C(=O)\text{-}R^* \end{array} + 3KOH \rightarrow C_3H_5(OH)_3 + 3R^*COOK \quad \ldots\ldots (2)$$

Fat and Oil → Glycerol + Soap

Hydrolysis of Soap by Acid

$$CH_3\text{-}(CH_2)_{16}\text{-}C(=O)\text{-}ONa + H^+ + Cl^- \rightarrow CH_3(CH_2)_{16}\text{-}C(=O)\text{-}OH + Na^+ + Cl^- \quad \ldots (3)$$

Soap + Acid → Fatty Acid

System of Analyses

The following system of analyses is presented here as a simple and practical procedure of analyzing sewage grease for various main constituents. The analyses are those which may be found in standard literature references (4) on analysis of fats and oils, but which were modified and adapted for use on sewage grease. As an example, in order to determine the per cent soap in the grease extract a neutral extrac-

* R is an alkyl radical.

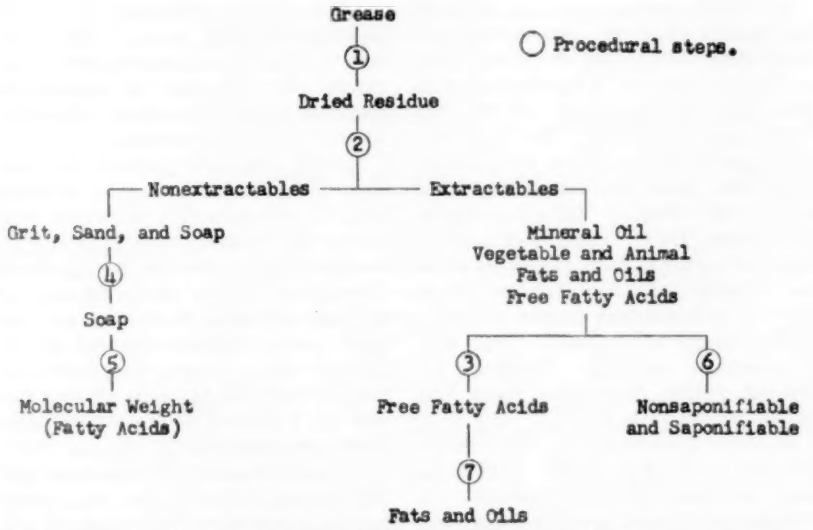

FIGURE 1.—Diagram of a system for the qualitative analysis of sewage greases.

tion was performed first with petroleum ether, which did not appreciably extract the soaps. The soaps were later extracted by acidifying the residue from the neutral extract and re-extracting the liberated fatty acids with petroleum ether (Figure 1). These are general analyses and may be used on other materials of similar composition. This system is presented merely as an outline and guide and it is not intended as a detailed laboratory procedure.

After separation of the grease into the different components, no further effort was made to identify the fractions by testing for physical properties or by determining chemical properties such as iodine number, Reichert-Meissl number, or acetyl number. However, these analyses may be performed if further identification of the separate saponifiable fractions, as well as a further breakdown of the nonsaponifiable fraction, is desired.

Procedure

1. Determination of Moisture. Weigh sample in a tared dish and dry at 103° C. to constant weight.

2. Neutral Extraction (mineral oil, fats and oils and free fatty acids). Extract (without acidification) the dried residue from the moisture determination in a Soxhlet or Goldfisch extractor with petroleum ether for 4 hr. This gives complete extraction of the vegetable and mineral oils, animal fats, and free fatty acids. The soaps are not appreciably extracted. Alternate methods such as extracting the dry finely pulverized material several times with ether in a separatory funnel may also be used.

The ether is evaporated on a steam bath and the grease dried in a tared dish at 103° C. to a constant weight. The increase in weight over a tared dish is the weight of the extracted grease.

3. Determination of Free Fatty Acid. The free fatty acid in the neutral ether extract may be determined by dissolving a weighed portion of the extracted grease (Procedure 2) and titrating directly with 0.10N NaOH to a phenolphthalein end point. The molecular weight of 282 (Procedure 5) may be used to calculate the per cent of free fatty acids.

4. Determination of Soap. Acidify the residue from the neutral ether extract with HCl to pH of 1.0 and heat on steam bath for 1 hr. in order to hydrolyze the soaps and set free the fatty acids. Extract this acid hydrolyzate in a separatory funnel with petroleum ether and wash the ether layer with distilled water to remove any excess HCl. Transfer the ether layer into a tared flask, evaporate ether on a steam bath and dry sample at 103° C. to a constant weight.

The weight of extracted fatty acid is calculated as soap. Example, extracted weight fatty acid times 1.07 equals weight of soap.

5. Determination of Molecular Weight of the Free Fatty Acid from the Acidified Ether Extract. A weighed amount of the free fatty acid is titrated with 0.10N NaOH to a phenolphthalein end point. The molecular weight is calculated as follows:

$$\text{M.W.} = \frac{\text{Sample (g.)} \times 1{,}000}{\text{Base vol. (cc.)} \times \text{Normality}}$$

6. Determination of Nonsaponifiable and Saponifiable Matter on Grease Extract. The per cent total saponifiable matter and nonsaponifiable oil may be determined by refluxing a weighed portion of the extract (Procedure 2) with a measured volume of 4 per cent alcoholic KOH for 30 min. A blank is run simultaneously. The sample mixture and blank are then titrated with standard 0.50N HCl to the phenolphthalein end point. The difference in titration volumes is used to calculate the per cent of saponifiable and nonsaponifiable matter. Molecular weight of 282 is assumed.

As an alternate method, the nonsaponifiable material may be extracted from the mixture with petroleum ether before the titration with HCl and the nonsaponifiable fraction is determined directly by drying and weighing. If the saponification is run on an acid-ether grease extract instead of the neutral ether extract, the result will then include the per cent of soap that was not measured in the neutral ether extract in Procedure 2.

7. Determination of Fats and Oils. The grease extracted by the neutral method (Procedure 2) consists of nonsaponifiable material, free fatty acids, and the animal and vegetable fats and oils. Therefore, by subtracting the nonsaponifiable fraction and the free fatty acids from the neutral grease extract, the fats and oils are obtained by difference. (For purpose of simplification the glycerol portion is assumed to be in the nonsaponifiable fraction.) The calculation is as follows:

Neutral extract (%)
− [Nonsaponifiable (%)
+ free fatty acids (%)]
= Fats and oils (%)

TABLE I.—Analysis of Sewage Treatment Plant Grease Samples

Sample	Grease Fraction (%)						
	Moisture	Non-extractable Material*	Non-saponifiable Material	Saponifiable Material†			
				Free Fatty Acids	Fats and Oils	Soap	Total Per Cent
Bar screen floatables	19.9	5.4	7.0	17.3	48.3	2.1	67.7
Primary skimmings	48.6	6.8	0.2	11.4	31.0	2.0	44.4
Aerator wall deposits	67.2	13.6	2.0	7.8	8.4	1.0	17.2
Final tank skimmings	67.8	12.2	1.3	10.8	7.1	0.8	18.7

* By difference.
† Based on ether extracts.

TABLE II.—Analysis of Grease Samples (Table I) Calculated on Moisture and Nonextractable Free Basis

Sample	Grease Fraction (%)				
	Non-saponifiable Material	Saponifiable Material*			
		Free Fatty Acids	Fats and Oils	Soap	Total Per Cent
Bar screen floatables	9.1	23.2	65.0	2.7	90.9
Primary skimmings	0.5	25.5	69.5	4.5	99.5
Aerator wall deposits	10.0	41.6	43.2	5.2	90.0
Final tank skimmings	6.5	54.0	35.5	4.0	93.5

* Based on ether extracts.

Study

Four samples of sewage grease were collected at a sewage treatment plant during various stages of treatment and analyzed for moisture, grease, and unextractable material. The extracted grease was further broken down into fats and oils, free fatty acids, soaps, and nonsaponifiable matter.

Data

The results of the grease sample analyses are summarized in Table I. Because of the variation in moisture and nonextractables, results are also expressed on a moisture and non-extractable material free basis for the purpose of better comparison (Table II).

Discussion

As the grease goes through the various stages in the treatment plant the free fatty acids increase and the fats and oils decrease. This is due to the splitting of the fats into free fatty acids and glycerol by enzymatic action, bacteria, and chemical and physical agents.

The normal sewage grease content from the particular treatment plants studied consisted of 85 to 95 per cent saponifiable matter, expressed on the ether extractable fraction.

Summary

A general method of sewage grease identification is presented that can be applied to sewage and industrial wastes.

Samples of sewage grease from a treatment plant were analyzed for the various constituents of the petroleum ether extracted fraction. These fractions were grouped into two main parts, a saponifiable fraction and a nonsaponifiable fraction. The former fraction consisted mainly of free fatty acids, soaps, and vegetable and animal fats and oils.

The nonsaponifiable fraction was not broken down into its various components, because it totaled only 5 to 10 per cent of the total extractable fraction. The nonsaponifiable fraction generally consists of hydrocarbons, waxes, sterols, and various other substances such as carotinoids.

Acknowledgment

The authors acknowledge with appreciation the suggestions of Remo Navone, Chief, Branch Public Health Laboratory, Division of Laboratories, Department of Public Health, State of California.

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INTERESTING EXTRACTS FROM OPERATION REPORTS

"Always begin somewhere—you can't build a reputation on what you are going to do."—*Anon.*

Attention operators! It will be appreciated if copies of the annual reports of both large and small sewage and industrial waste treatment plants are sent to the Federation office for abstracting in this section of the Journal. Please direct annual reports to: The Operator's Corner, SEWAGE AND INDUSTRIAL WASTES, 4435 Wisconsin Ave., N.W., Washington 16, D. C.

Annual Report of the Greater Winnipeg (Man.) Sanitary District for the Years 1954 and 1955 *

BY N. S. BUBBIS, *General Manager*

Virtually all of the construction work on the extensions to the main sewage treatment plant was completed by December, 1954. It is estimated that at the present rate of growth the treatment facilities should be adequate for about 10 years.

As a result of the data obtained since 1950 from the experimental operation of the small sludge lagoons, the following recommendations were made by the consulting engineers:

1. The basic method of sludge dewatering should be by the use of lagoons.
2. Vacuum filters should be installed to assure successful operation under all conditions and to provide flexibility.
3. Additional elutriation facilities should be provided.

During 1955 four new lagoons with a capacity of 68 acre-feet were constructed. A new rotary vacuum filter, which uses stainless steel as the filter medium, was installed. The existing elutriation tanks were enlarged.

Agreements were executed in mid-1954 whereby the three non-member municipalities re-entered the Greater Winnipeg Sanitary District, as required by Provincial legislation. The District's position was clarified by making it responsible for the control of pollution in the rivers within the District's boundaries.

As a result of this, and in the continuance of the efforts to control industrial wastes, two bylaws were enacted by the District. One defines the character of the sewage and industrial wastes which would be accepted into the sewer system; it also specifies that pretreatment of industrial wastes shall be provided where necessary.

* For last previous extract see THIS JOURNAL, **27**, 3, 343 (Mar., 1955).

TABLE I.—Summary of Operating Data, Greater Winnipeg Sanitary District, for the Years 1954 and 1955 *

Item	Average 1954	1955
Population served	328,305	377,400
Precipitation (in.)	26.0	22.8
Sewage flow (m.g.d.)	33.7	28.9
Grit (cu. ft./m.g.)	1.1	2.2
Settleable solids:		
Plant influent (ml./l.)†	5.9	6.4
Clarifier effluent (ml./l.)	1.2	—
Removal (%)	79.7	—
Suspended solids:		
Plant influent (p.p.m.)†	285	270
Clarifier effluent (p.p.m.)	100	—
Removal (%)	64.9	—
B.O.D., 5-day:		
Plant influent (p.p.m.)†	280	280
Clarifier effluent (p.p.m.)	135	—
Removal (%)	48.1	—
Sludge gas:		
Produced, total (mil. cu. ft.)	70.0‡	133.7
Used for heating, total (mil. cu. ft.)¶	35.0‡	55.36
Wasted, total (mil. cu. ft.)	35.0‡	78.34
Methane (%)	67.5	67.3
Sludge lagoons:		
Dig. sludge pumped, dry solids (mil. lb.)	—	4.45
Sludge removed, dry solids (mil. lb.)	—	1.65
Cost of operation ($):		
Administration and debt charges	—	143,919.12
Collection	82,175.45	85,934.49
Treatment	211,160.27	156,323.08
Total	293,335.72	386,176.69

* All flows and capacities in U. S. gallons.
† Includes solids in elutriate and filtrate returns.
‡ Estimated.
¶ Does not include clarifier heating.

The second prohibits the discharge or drainage of sewage within the District into any river flowing through or adjacent to the District. During 1955 considerable investigational work was undertaken on the control of industrial wastes and a number of industrial wastes licenses were issued.

Operation of the pumping stations and treatment facilities continued to be satisfactory. The spring flood in 1955 required operation, for the first time, of 15 of the 21 flood pumping stations of the Greater Winnipeg Dyking Board. The District was given the responsibility in 1952 for inspecting and maintaining these stations. The actual operations were successful and disclosed strengths and weaknesses in the system.

A summary of the 1954 and 1955 operating data is given in Table I.

1956 Operation Report of the Papillion Creek Sewage Treatment Plant, Omaha, Nebr.

By Carl Chin, *Chemist*

One of the largest activated sludge plants in the Great Plains, the Papillion Creek Sewage Treatment Plant, was placed in operation in 1941 to serve a portion of Omaha. Nebr. The treatment facilities provide for activated sludge treatment of 6 m.g.d., with capacity for handling peak flows

up to 9 m.g.d. Flows greater than this must be by-passed after primary treatment only. Peak flows during the summer months frequently exceed 9 m.g.d.

Omaha had a 1950 population of 251,000 and is ranked as a large and rapidly growing livestock and industrial center.

Somewhat belated efforts are being made to increase the percentage of sewage treated and thereby reduce pollution in the Missouri River.

Treatment Units

The treatment plant is located on a 40-acre diked area along Papillion Creek and receives raw sewage through an 18-in. and 48-in. outfall sewer. Manually-cleaned bar grates precede the grit chambers, where two grit channels provide 50-sec. detention. The screenings are buried and the grit is used for landfill on the plant site.

Two comminutors follow the grit chambers. Flow proceeds to three rectangular clarifiers. Flow through the plant is by gravity.

Four floating cover, heated digesters handle the solids load and furnish sufficient gas for heating the digesters and administration building. Digester No. 1 was cleaned in the summer of 1955. The tank contents were pumped to a sludge lagoon. Considerable difficulty was encountered in removing the heavy accumulation of grit and other material. Water was pumped under pressure from the primary clarifiers to loosen and dilute the accumulated material. The other digesters carried the solids load until digester No. 1 was seeded and returned to service. Digester No. 3 was similarly dewatered and cleaned in the summer of 1956. The other digesters will be cleaned subsequently.

TABLE II.—Summary of 1956 Operation Data, Papillion Creek Sewage Treatment Plant, Omaha, Nebr.

Item	Average	Item	Average
Rainfall (in.)	23.27	Raw sludge:	
Temperature (° C.)	52.50	Pumped per day (cu. ft.)	4,520
Population:		pH	6.6
Connected (estimated)	50,000	Dry solids (%)	8.5
Equiv	73,000	Volatile solids (%)	52.0
Sewage flow (m.g.d.)	4.85	Activated sludge data:	
Grit (cu. ft./m.g.)	6.10	Aeration (hr.)	5.2
pH:		Air consumption (cu. ft. per gal. sewage)	0.94
Influent	7.6	Returned sludge (% by volume)	32.5
Primary effl.	7.6	Mixed liquor suspended solids (p.p.m.)	3,080
Final effl.	7.4	Sludge index	102
Settleable solids:		D.O., aeration tank (p.p.m.)	1.0
Influent (ml./l.)	5.33	Returned activated sludge (p.p.m.)	11,300
Primary effl. (ml./l.)	0.82	Digested sludge:	
Reduction (%)	84.5	To drying beds (cu. ft. per day)	550
Suspended solids:		pH	7.4
Influent (p.p.m.)	610	Dry solids (%)	13.3
Primary effl. (p.p.m.)	260	Volatile solids (%)	31.5
Final effl. (p.p.m.)	130	Power (kw.-hr. per day)	2,380
Reduction (%)	78.8	Outlet stream analysis (p.p.m.):	
B.O.D., 5-day:		Upstream ½ mile:	
Influent (p.p.m.)	300	D.O.	8.1
Primary effl. (p.p.m.)	172	pH	7.8
Final effl. (p.p.m.)	82	Downstream ½ mile:	
Reduction (%)	73	D.O.	5.3
Gas production:		pH	7.5
Total (mil. cu. ft.)	25.7		
Daily average (cu. ft.)	70,000		
Cu. ft. per lb. (dry) volatile solids added	6.8		

Digested sludge is air-dried on four 36-ft. by 28-ft. glass-covered drying beds. There is an excellent demand for the ground sludge, which is sold to the public as a soil conditioner.

The settled effluent is metered to the two double-pass aeration tanks, 27 ft. by 120 ft. by 15 ft., which provide standard tapered aeration. Swing diffusers provide up to 1 cu. ft. of air per gallon of sewage treated. The capacity of the two blowers is rated at approximately 7,500 c.f.m. Returned sludge amounts to 25 per cent of the sludge. Final settling is provided by two 75-ft. circular clarifiers. The excess sludge is returned to the primary clarifiers.

Operation and Maintenance

Maintenance has been routine. Equipment repairs have included overhauling and replacing worn parts in the communitors, and new chains, flights and parts for the sludge removal equipment in the No. 3 primary clarifier. The carborundum diffuser tubes were replaced with Saran-wrapped tubes.

Froth on the aeration tanks made operations hazardous and unhealthful. Wind-borne froth ruined landscape plantings and created odorous and unsightly conditions on the building walls. A system of water sprays successfully controlled the froth under normal conditions. Defrothants have been used, but the cost is prohibitive. Additional study is necessary to successful control of the froth under emergency conditions.

Certain grease and froth problems occurred on the aeration tanks during cold weather. Gummy, sponge-like masses floated on the tanks. The problem was traced to grease from a meat packer and controlled by requiring pretreatment of the waste.

Operating data for 1956 are presented in Table II.

Report of the Cincinnati, Ohio, Sewage Disposal Program for 1954 and 1955 *

By A. D. Caster, *Sewage Disposal Engineer*

The sewage treatment program for the Cincinnati Metropolitan Service Area made rapid strides forward in the construction of system facilities and the organization of operations. Construction work on the Little Miami system was completed and the major share of the construction for the Mill Creek system was under contract.

Organization

The Sewage Disposal Section was reorganized on the basis of a typical industry (Figure 1). A close parallel can be drawn between the treatment of sewage (the process of producing at reasonable cost an acceptable finished product—effluent) and industrial processing (in which raw materials are utilized to produce a marketable product).

The responsibilities of the various operations have been placed under separate sections in order to obtain better control of personnel and equipment. The Sewage Treatment Section is responsible for the processing of the sewage from raw to final effluent and for the utilization and disposal of the by-products. Ultimately there will be three plants operating under this section. The departmental Accounting and Records Section maintains revenue and expenditure accounts and personnel records. The Engineering Section plans and designs facilities in conjunction with the consulting engineers. The Industrial Waste Control and Revenue Engineering Section maintains a constant check on the industrial wastes and related revenues. The Control Engineering Section provides essential laboratory services for

* For last previous extract see This Journal, 27, 7, 862 (July, 1955).

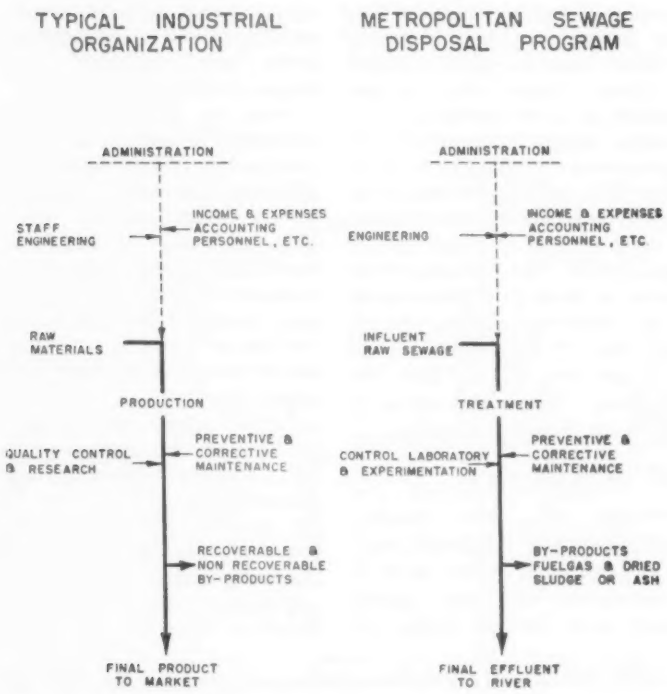

FIGURE 1.—Comparison of sewage treatment organization with that of an industry.

treatment plant, industrial wastes, and stream pollution.

In addition to the preceding five sections, three new sections were established for operation in 1956 (Figure 2). The Maintenance Section will provide routine and preventive maintenance services for all treatment plants, sludge disposal, power facilities, buildings, regulating chambers, and other physical properties. Its work will cover equipment, structures, grounds, and conduits.

The Power Section will be responsible for the proper and economical operation of the power plant at the Mill Creek Disposal Works.

The Safety and Personnel Section will develop a safety program for all personnel. Included will be educational activities, promotional literature, plant safety committees, accident reporting, statistical studies, and cooperation with various safety groups.

Accounting and Records

The accounting unit performs a wide variety of services and functions essential for financial control, management, and long-range planning incident to a facility which will have a total investment of nearly $50 million. Operating revenues average $4.5 million. Income for 1955 showed a decrease, principally from lower sewer service charges resulting from a reduction by industry in the strength of its wastes. The decrease in interest from invested construction money will continue as the construction program advances and payments are made to the contractors.

In addition to construction finances and service charges, the accounting

unit keeps personnel records, payroll, and complete cost records, including operating costs on all motor vehicles.

Control Engineering

Laboratory services performed by this section include:

1. Measuring the effectiveness of sewage treatment.
2. Analyzing samples of industrial wastes.
3. Making explosive gas determinations.
4. Sampling and analyzing river water.
5. Conducting process improvement research.
6. Coordinating flood control activities.
7. Furnishing technical and engineering advice in the evaluation and interpretation of the scientific data developed by the laboratories.

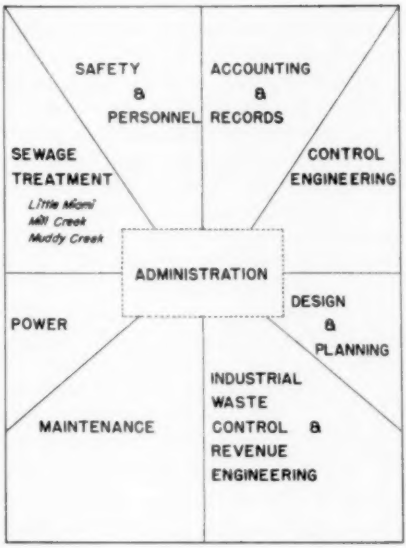

FIGURE 2.—Organization of the Sewage Disposal Section, Cincinnati, Ohio.

At present, laboratories are maintained at the Little Miami Works for plant control and industrial waste studies. The completion of an Administration Building at the Mill Creek Sewage Works in 1956 will provide adequate quarters for the laboratory staffs.

A central stockroom of laboratory supplies was set up with sufficient supplies purchased to meet estimated requirements for two years. Case-lot purchases by competitive bidding were estimated to reduce the final cost to $12,000, a 40 per cent saving.

The Little Miami laboratory analyzed 3,756 samples in 1955. The industrial waste laboratory analyzed 1,521 industrial samples. Surcharges to industry are based on the analysis of the industry's waste.

Stream pollution survey work is undertaken by this section in order to ascertain the quality of water in the Cincinnati Pool on the Ohio River into which Cincinnati discharges its municipal and industrial wastes. The permit from the Ohio Water Pollution Control Board requires that the following standards be maintained:

1. Substantially complete removal of settleable solids.
2. Removal of not less than 45 per cent of the total suspended solids.
3. Reduction of the B.O.D. by not less than 65 per cent, provided that whenever conditions permit a lesser degree of reduction (but not lower than 35 per cent) may be applied provided a minimum of 4.0 p.p.m. of dissolved oxygen is maintained in the Cincinnati Pool(at the bottom of the oxygen sag curve).

Dissolved oxygen and coliform determinations were made at representative points on the river. Bottom material was sampled twice in the summer of 1955.

Explosive gas testing is another function of the Control Engineering Section. A well-equipped mobile laboratory was placed in service in 1954 to provide on-the-spot determinations of materials in the sewers. As a sup-

porting unit, a spectrophotometer is used to aid in the positive identification of suspected materials.

As an example, a source of a large volume of extraction solvent was located in a suburb of Cincinnati. Positive identification was made with the spectrophotometer, using the material from the suspected company as a standard. On the basis of this evidence the company removed all volatiles from the sewers. Elimination of this one explosion hazard more than justified the original cost of the mobile laboratory and spectrophotometer.

Plans for industrial waste treatment facilities within the jurisdiction of the Cincinnati Metropolitan Service Area are submitted to this section for review and approval.

Design and Planning

Design and construction activities centered on the Mill Creek Disposal Works and the related sewer system and structures. Plan checking was carried out with the consulting engineers. Design work included interceptors. Other activities included preliminary reports, surveys, easements, specifications, estimates, and liaison with the city's construction section.

Industrial Wastes

During 1954 the industrial wastes laboratory directed its efforts to the equitable application and administration of the sewerage service charge. This required the investigating and processing of many accounts. Industry spent between $4 million and $5 million during 1954 on the installation of facilities to treat wastes partially or completely.

A mobile gaging unit was developed by the section to gage and sample flows in the sewers.

The section conducted extensive gaging activities. In 1955, for example, 44,588 flow measurements were made and 44,588 samples collected. All outfall sewers which will contribute to the proposed Muddy Creek Sewage Works were gaged and sampled.

Among the projects undertaken and completed by this section were the following:

1. Four monitor stations were established on the Mill Creek Interceptor for the detection of explosive gas material.
2. All interceptor connections tributary to the Little Miami Sewage Disposal system were located, described, and mapped.
3. Circular weirs for gaging sewer flows were developed to overcome the problems caused by the settling of material behind standard weirs. The circular weir has proven accurate over a wide range of flows; it serves as a weir for low flows and as an orifice for high flows.
4. Automatic samplers were studied as a result of the high turnover and irresponsibility of gaging and sampling personnel. Adaptation to the widely varying conditions of installation in sewers is the principal problem to be overcome.
5. Plywood shelters with oil heaters were developed to protect gaging and sampling personnel from inclement weather and low temperatures.

The waste surveys and subsequent analyses of samples in 1953 and 1954 indicated that about 36 major industries contributed almost 83 per cent of the high-strength wastes.

The wastes of 16 industries were again analyzed to determine any change in characteristics. Increased strengths of waste were detected at 13 companies and the surcharges were raised accordingly. Three companies had decreases in waste strengths, which resulted in a decrease in service charges.

Re-surveys, made at the request of industry to confirm a previous analysis, were performed on 15 wastes. The industries paid the major share of the re-survey expenses.

Surcharges were paid by 244 companies, classified as follows:

Industry	No.
Laundry	60
Meat	55
Food	24
Dairy	24
Metal	20
Chemical	14
Lithography	11
Brewery and distillery	6
Paper	6
Textile	5
Miscellaneous	5
Soap	4
Ceramic	4
Tannery	3
Railroad	2
Oils	1

This is a reduction from the 272 plants paying charges in 1954.

Industry did everything possible in 1955 to conserve water and reduce waste strengths in an effort to reduce the expense of service charges as well as the surcharges. The results have both a favorable and an unfavorable effect on the sewage disposal program.

Longer equipment life and lower operating costs, resulting from a reduction in the strength of the industrial wastes, are real benefits. On the other hand, plant facilities were designed to handle the industrial waste load indicated by analyses made in 1950–52. The additional plant capacity was provided at the urging of industry. However, a decrease in revenue from industrial waste charges could jeopardize the entire program.

Within the confines of the Cincinnati Metropolitan Service Area are 54 industries that wholly or partially discharge effluent to state waters, contrary to the directives of the Ohio Water Pollution Control Board and the Ordinances, Rules, and Regulations of the City of Cincinnati.

Initial action by the Sewage Disposal Section has brought all these companies to the attention of the Ohio Board. Most of these industries hold temporary permits to discharge their wastes. The work of the Sewage Disposal Section has resulted in considerable improvement in the waste disposal practices of the industries, as follows:

Companies (No.)	Action
16	Separated cooling water
6	Installed septic tanks
8	Diverted waste to sewerage system
14	Given time to study problem
7	Under investigation
3	Referred to Ohio Board

Little Miami Sewage Works

The year 1954 may perhaps best be described as a transition period in which the construction phase of the Little Miami project was substantially completed, the plant structures and equipment were given actual operational tests and, finally, an operational routine was established. The treatment works, as a unit, has performed in such a manner as to indicate that plant efficiencies are obtainable commensurate with plant design. The full complement of personnel (33) was employed. Valuable technical assistance on plant operational problems was provided by contract with the consulting engineers.

The sludge digestion system remained in the acid stage until October, 1954, when a "normal" routine was established. The digester difficulties appeared to be caused by the excessive loading of the digesters without due regard for the build-up of volatile acid concentration during the first months of operation.

A number of operational difficulties were apparent and their solution awaits further experience.

During 1955 the treatment facilities removed 5.3 tons of screenings, 156.3 tons of grit, and 3,120 tons of suspended solids from the raw sewage for accepted "yardsticks" of plant performance of 58.7 per cent suspended solids removal and 42.9 per cent B.O.D. removal. Although chemical treatment facilities are available, they were not used.

TABLE III.—Operating Data for the Little Miami Sewage Works, Cincinnati, Ohio, for 1954 and 1955

Item	Average 1954	1955
Flow* (m.g.d.)	12.36	13.5
Rainfall	37.14	41.94
Screenings, wet (lb./m.g.)	17.2	10.9
Grit (cu. ft./m.g.)	1.79	1.34
Total solids, raw (p.p.m.)	828	813
Suspended solids:		
Raw (p.p.m.)	317	269
Effluent (p.p.m.)	140	111
Removed (%)	55.8	58.7
B.O.D.:		
Raw (p.p.m.)	185	126
Effluent (p.p.m.)	108	72
Removed (%)	41.1	42.9
Sludge, raw†:		
Total, dry (million lb.)	8.67	8.96
Solids (%)	8.98	7.81
Volatile (%)	61.32	61.9
pH	6.0	6.1
Gas‡:		
Produced (1,000 cu. ft.)	26,484	45,117
Utilized	9,269	22,441
Filtration¶:		
Cake, wet (tons)	3,049.93	6,352.63
Solids (%)	34.9	33.0
Volatiles	40.6	45.4
Chemicals:		
$FeCl_3$ (lb.)	38,640	195,260
Feed (%)	14.96	5.05
Incineration:		
Sludge, dry (tons)	528.05	1,934.6
Ash, dry (tons)	323.0	1,088.4
Cost (per m.g.)	30.81	30.81

* Includes all recycled liquors. Raw sewage samples are not affected by recycled flow.
† Includes solids from recycled plant processes.
‡ Quantities are "as metered"; waste gas not metered.
¶ Four months operation in 1954 (Sept., Oct., Nov., and Dec.).

The treatment plant was shut down for 29 days in March due to flood conditions of the Ohio River. During this period the flood control program was tested.

The digesters were not fed during the flood; as a result, daily gas production dropped from 50,000 cu. ft. to 2,600 cu. ft. in 33 days. When the feeding of solids was resumed at the same rates as before the flood, both the primary and the secondary digesters quickly became acid. With careful control, normal operation was established in three weeks.

The Saran-wound, stainless steel, pre-aeration tubes were replaced with T-shaped air-jet pipes made from 9-in. lengths of ¼-in. pipe. The jets were set so the "T" was parallel to the channel wall and 12 in. above the floor. This change eliminated the necessity for frequent tube cleaning.

Digested sludge, elutriated at minimum design rates, would not concentrate sufficiently to give adequate yields on the vacuum filters. The use of lime and ferric chloride as a conditioner for the elutriated sludge was tried on a plant scale. The combination produced a yield of 4 lb. of filter cake per square foot of filter area per hour, as compared with 1.9 lb. for ferric chloride alone.

Chlorine was used for odor control in August and September.

The bucket elevator handling ash from the incinerators required excessive maintenance. Sprockets and chains of improved designs and materials will be used in 1956. Corrosion and scale caused by the use in the pump seals of well water with a high dissolved mineral content will be eliminated by using city water with proper cross-connection protection.

Operating data are given in Table III.

TIPS ON SLUDGE DRYING BED CARE

By Melvin Bowers

Sewage Plant Operator, Lebanon, Tenn.

Editor's Note—This paper is of particular interest in view of the fact that Mr. Bowers is the champion sludge drying bed man in Tennessee. During 1956 he drew 17 beds of sludge or 5.67 beds per bed available. His record for a two-month period is 11 beds drawn with only three beds available. It is pertinent to note that in 1956 the population equivalent to the plant on a B.O.D. basis averaged about 10,000 daily.

In the experience of the author, four things contribute very materially to the maintenance of clean, well-drained sludge drying beds. These are: (a) use of a good grade sand for top layer; (b) drawing of a well-digested sludge; (c) thorough cleaning of beds; and (d) adequate rotation of beds.

Top Layer Sand

Use of a good grade of sand for the top layer is essential. The author prefers a washed "Bird-Eye" sand with an effective size of 2.0 mm. Sludge drying beds should be re-sanded every three years, or as often as is necessary to compensate for the loss of sand each time sludge is removed.

Sludge Drawing

A well-digested sludge, containing a substantial quantity of gas, should be drawn. The sludge should be discharged as slowly as possible in order not to run the risk of pulling a hole in the digester sludge blanket. If these precautions are not taken, the result will be a thin, watery sludge with too much moisture content.

Cleaning of Beds

Each time a bed is cleaned of dried sludge, it is important to take up all the little pieces and small slugs of sludge. The time necessary to rake up and dispose of all small pieces is well spent. While this adds to the time necessary to clean a bed, it saves time and work later on. If bits of dried sludge are left on the beds, they will be stepped on and mashed into the sand and eventually will seal the beds. If this is allowed to occur the beds will drain slowly at best and, in time, will get so dirty that they will not drain at all. When this happens the only thing that can be done is to plow up the beds, throw away the old dirty sand, and start new beds with fresh sand.

Rotation of Beds

Most sewage plant operators do not have enough drying beds and therefore tend not to rotate them as frequently as they should. At the Lebanon Sewage Treatment Plant, there are only three beds, each measuring 73 ft. by 26 ft. by 1 ft., with an area of 1,898 sq. ft. or a total of 5,694 sq. ft. In

the spring it is particularly hard to find time to rotate, but the rotation of beds is essential and every effort is made to do so even under these conditions. Best results are claimed from drawing sludge to a depth of 7 in. or 8 in. rather than 10 in. or 12 in. Sludge drains better, cracks faster and, in the course of a year, more use of the available bed area is obtained.

TIPS AND QUIPS

Stable Starch Indicator Solution

The search for a stable starch indicator solution for use in making dissolved oxygen determinations continues. Previously a starch solution, using glacial acetic acid as a preservative, was reported on by Terry Masuda, Public Health Chemist, State of California (THIS JOURNAL, **27**, 3, 352; Mar., 1955).

Recently A. F. Westerhold, Chemist, Sanitary Bacteriology and Chemistry Laboratory, Illinois Department of Health, Springfield, Ill., submitted his preparation for a stable starch solution. The solution is prepared by adding a combination of 0.4 per cent sodium propionate and 0.2 per cent sodium azide to the starch solution of Platner.*

Westerhold reports that several preservatives were tried before the propionate-azide solution was developed. The mold growths are inhibited and the starch solution has remained stable for six months or longer. Its use has been particularly successful in D. O. field kits as well as in the laboratory.

Keep Up Your Shots

When the incidence of a former dread disease decreases until its occurrence is less than common, we become self-complacent concerning the possibility of its attack upon ourselves or our families.

Diphtheria is one of these diseases. According to the United States Public Health Service, more than 2,000 cases are still reported in the United States every year. The country as a whole had 18 per cent more cases in 1956 than in the preceding year.

When diphtheria was more prevalent, those who acquired immunity from shots or from having the disease received "nature boosters" by being exposed to the disease from time to time. Today children, and adults too, lose their immunity if they do not "keep up their shots."

Keeping up one's shots is good advice for all sewage treatment plant personnel to heed. Tetanus and typhoid boosters (if you have had the series) should be taken promptly. The dangers of infection during the summer season should be particularly apparent. Also plant personnel should consider the protection afforded by polio shots. Consult your physician and, if the season is not too far advanced in your locale, plan for your shots now.

The hypodermic needle—instrument of preventive as well as curative medicine—may mean the difference between life and death for you or a member of your family.

Clean Streams Tour

Always conscious of the need for promoting an effective public relations program on stream pollution, the Pennsylvania Member Association was cosponsor, with 18 cooperating agencies

* Platner, W. S., *Anal. Chem.*, **16**, 369 (1944).

and the Pennsylvania State Chamber of Commerce, in a recent Pennsylvania Clean Streams Conference at the Mellon Institute of Industrial Research, Pittsburgh, Pa.

A particularly interesting feature of this, the fifth annual conference, was a river trip on the Monongahela, Ohio, and Allegheny rivers.

Wisconsin Operators Certified

Wisconsin sewage works operators took the first certification examination in Wisconsin history on April 26, 1957. This examination for "certification and registration of State of Wisconsin sewage works operators" was given under a voluntary plan which was adopted in 1956. The 116 operators taking the examination were in attendance at the 15th Wisconsin Sewage Works Operators Short Course, held at the University of Wisconsin, Madison, Wis. The short course is sponsored by the League of Wisconsin Municipalities and the Conference of Wisconsin Sewage Works Operators, with the Wisconsin State Laboratory of Hygiene, the University of Wisconsin, and the Wisconsin State Board of Health cooperating in the presentation of the course material.

The operator certification program is designed to improve the caliber of sewage works operation through the employment of trained, experienced, reliable, and efficient personnel, and to provide an opportunity whereby sewage works personnel can demonstrate competency and improve their status.

The Wisconsin Conference of Sewage Works Operators elected the following officers:

President: Earl Probst, Appleton.
Secretary-Treasurer: Charles Kelley, Elkhorn.
Directors: C. W. Bogenhagen, Fond du Lac.
James Richgruber, Sparta.
Roger Scovill, Madison.

The former president was Frank Vilen, Kenosha.

Oregon Certification Program

Although the report of the Operator's Qualification Committee (THIS JOURNAL, **29**, 2, 218; Feb., 1957) listed Oregon as one of four states not having some type of sewage treatment plant certification, word has been received that a voluntary program was initiated in 1956. A total of 17 operators are presently certified.

Iodine Disinfection

Interest in the use of iodine as a disinfectant and sanitizing agent was expressed at a symposium on the subject at the recent 131st National Meeting of the American Chemical Society.

Inexpensive iodine preparations, safe for human use, have been developed. It was reported that iodine in the concentrations used for drinking water disinfection will kill amoeba cysts, which chlorine will not. Iodine is also effective against the virus which causes infectious hepatitis.

The preparation of idophors, mixtures of iodine and a carrier to make the iodine more water soluble and increase its stability in water, together with a decrease in the cost of iodine, holds promise for increased use of iodine as a disinfectant. Among iodine-unique properties is the persistence of the amber iodine color, as a "built-in" color indicator, as long as a solution is effective as a disinfectant.

Unladylike?

The first graduate student on the distaff side in 15 years recently enrolled in the Department of Sanitation at Rutgers University. The lady student hails from North Wales, where she works for Monsanto Chemicals Ltd. She plans to learn modern techniques

of sewage and industrial waste disposal.

Women are not new to the field of sewage treatment. Many have worked in the administrative offices and others have assisted plant operations through their work in the treatment plant laboratories. However, not many women take up the "unladylike" occupation in the technical aspects of the sewage and industrial waste treatment field.

Leasing Treatment Facilities

The leasing of waste treatment facilities affords an industry the same accounting advantages as leasing manufacturing facilities. The annual charge made to the operating company (lessor) becomes a fixed charge which is a wholly deductible expense out of gross profits before taxes.

River Pollution on TV

The Potomac River pollution situation received TV time in April, May, and June of this year, when station WRC–TV, Washington, D. C., televised the third in a series of presentations on the river, entitled "Our Beautiful Potomac."

First aired in 1954, this series on the pollution menace in the Nation's Capital has received many public service awards, including the Sylvania TV Award. The new series will show the present status of the pollution problem in seven presentations.

As a further public service the Interstate Commission on the Potomac River * is making the TV-films available to interested civic groups.

Atomic Power Station

Radioactive wastes resulting from operation of the Shippingport (Pa.) Atomic Power Station will be treated in a treatment plant which occupies an area of more than one acre. Although the design involved no unusual structural problems, the structural work was approximately 40 per cent of the total plant cost. Particular attention was directed to the protection of operating personnel and the public from radioactivity.

Criteria governing the project included:

1. All tanks and pipes that may contain radioactive material were adequately shielded and preferably installed underground.
2. Tanks and pipes were installed underground in such a manner that no hidden leak can develop which might result in undetected radioactive contamination of the local ground water.
3. Shielding of operating personnel and treatment of the radioactive wastes was planned in accordance with conservative standards.

The Shippingport atomic power plant will be the first commercial power project to be placed in operation.

* 202 Transportation Bldg., Washington 6, D. C.

The man who does his work well—does it safely.

Editorial

BOSTON 1957

If you haven't already done it, it is time to red-letter the dates of October 7–10 on your calendar. During these days, the Federation will hold its 30th Annual Meeting in Boston—the first city except New York to be revisited as a Convention City.

Many Federation members will remember the warm hospitality of the New England Sewage Works Association as well as the interesting historical sights and renowned eating places during those delightful days of October 17–20, 1949. It was at Boston that the "Federation of Sewage Works Associations" became the Federation of Sewage and Industrial Wastes Associations and the Sewage Works Journal became SEWAGE AND INDUSTRIAL WASTES. Other important changes included authorization for monthly publication of the Federation Journal. The quarterly publication schedule of October, 1928 became bimonthly in 1932 and matured to monthly publication in January, 1950.

Although still referred to by many as the "Sewage Works Journal" and the "Sewage Works Associations" the Federation has made steady progress in serving industrial wastes interests. The 1949 Boston Meeting of the Federation Board of Control further demonstrated Federation interest in industrial wastes by creating the annual Federation Industrial Wastes Medal, given for noteworthy contributions to the JOURNAL by an employee of industry.

From the standpoint of attendance the 1949 Boston Meeting marked a new high in total (812) as well as in both men and ladies registration. Industrial wastes treatment personnel helped swell registration. The growth of the Federation since the previous Boston meeting is noteworthy. Now the Federation's Member Associations can boast a total membership of 7,200—a full 2,000 greater than in 1949. Much of this growth has come from industrial wastes membership growth. It was at the Boston Meeting that one most mindful of this growth potential, Art Niles of Toledo, ascended to the Federation Presidency.

Historical Boston was the natural setting for the Federation meeting of October, 1949. The significance of the 1957 meeting is impossible to predict. You may be certain, however, that this one grand gathering of those concerned with stream conservation will be a milestone of progress in water-carried waste treatment. The year's most complete equipment exhibits showing the manufacturers' latest developments will give a direct measure of this progress. Attendants expected from Europe will accentuate the Federation's international character. The technical program and inspection trips will be filled with both practice and theory of wastes treatment.

If you have never attended a Federation meeting, come to Boston to see what you've been missing. If you always attended, come to Boston to see the Host Association surpass its 1949 meeting. In either case, come and bring your wife for the incomparable meeting of the year!

Again—mark that calendar, October 7–10 for the Hotel Statler, Boston, Massachusetts,—and send in your reservation card now!

R. E. F.

Reviews and Abstracts*

Symposium on Basic Biological Principles for Purifying Chemically Polluted Waters:

1. **Introduction.** By H. Heukelekian. *Ind. Eng. Chem.*, **48**, 1403 (1956).

Because microbiological processes lie at the base of the purification of polluted waters, this symposium was arranged to draw from the basic biological sciences the concepts and information for understanding and interpreting the complex phenomena related to the purification of polluted waters.

2. **Microbial Adaptation.** By O. Wyss. *Ind. Eng. Chem.*, **48**, 1404 (1956).

The limits of microbial adaptation are wide. Much of it has occurred in the past so that organisms have developed enzymes which approximately fit any existing environment. The nature of some of the changes, the rates of expected changes and the mechanism of the manifestations of the changes are given by the author.

3. **Microbial Associations and Antagonisms.** By R. Weindling; Discussion by R. S. Ingols. *Ind. Eng. Chem.*, **48**, 1407 (1956).

The complexity of microbial relations interlocking in time and space pose formidable obstacles to comprehensive work. Investigators have concentrated, therefore, on selected microbial groups of special interest or on microbial associations in specific environments. The search for answers to practical problems has led, almost invariably, to the consideration of the interdependence of adaptive and associative microbial phenomena.

The discussion emphasizes the biological interrelationships of sewage purification processes.

4. **Transformation of Carbon Compounds by Microorganisms.** By W. J. Nickerson; Discussion by S. R. Hoover. *Ind. Eng. Chem.*, **48**, 1411 (1956).

The author has made liberal use of biochemical flow sheets or metabolic maps as guides in presenting the complex type of reactions exhibited by certain organisms in their transformations of carbon compounds. Only the carbon compounds with hydrogen and oxygen are discussed. The article is a review of the metabolic pathways of common food substances, highly resistant natural substances, and some newly synthesized compounds which cause stream pollution problems. There is an excellent bibliography. The discusser indicates how the basic research has aided an understanding of waste treatment processes.

5. **Biological Transformation of Nitrogen Compounds.** By C. C. Delwiche; Discussion by G. A. Rohlich. *Ind. Eng. Chem.*, **48**, 1421 (1956).

The article limits the discussion of nitrogen compounds to those of biological (and waste) significance; proteins and their amino acids, ammonia, nitrite, and nitrates. The chemistry of the various changes to the nitrogen atom are given. References are given to 103 articles.

The discusser includes the effects of chlorination upon the nitrogenous compounds of potable water and waste water.

6. **Transformations of Sulfur by Microorganisms.** By R. L. Starkey; Discussion by N. L. Temple. *Ind. Eng. Chem.*, **48**, 1429 (1956).

There are many compounds of sulfur found in nature; the valence of the sulfur

* Please send to Federation headquarters all periodicals, bulletins, special reports, etc., which might be suitable for abstracting in This Journal. Publications of public health departments, stream pollution control agencies, research organizations, and educational institutions are particularly desired. Address such material: Federation of Sewage and Industrial Wastes Assns., 4435 Wisconsin Ave., N. W., Washington 16, D. C.

can vary throughout its permissible range. Under anaerobic conditions, the negative 2 valence is the stable end product; while under aerobic conditions, the valence of the stable end product is positive 6. Many organisms are capable of chemical changes in the sulfur atom and some of the changes have great commercial importance. The sulfur also enters into photosynthetic reactions in a few species.

The importance of the acid mine drainage problem fully justifies the basic study of sulfur metabolism, according to the discusser.

7. **Biological Formation of Methane.** By H. A. Barker; Discussion by A. M. Buswell. *Ind. Eng. Chem.*, **48**, 1443 (1956).

Methane production is limited to a small group of anaerobic bacteria. For some obscure reason, all the known methane-producing bacteria are unable to decompose carbohydrates and amino acids. Generally, only the simple, small fatty acids and alcohols are used by these bacteria. They are extremely sensitive to small changes in pH and temperature. The chemistry of the formation of methane is given in detail.

The discusser indicates that methane-producing bacteria have found wide application in the treatment of industrial wastes.

8. **Microbial Decomposition of Hydrocarbons.** By J. B. Davis. *Ind. Eng. Chem.*, **48**, 1444 (1956).

Microbiologists have found that hydrocarbons are utilized by certain bacteria and fungi, but at a lower rate than the common foods. Patent applications have been filed for the use of microbial decomposition in the waste treatment of petroleum derivatives.

9. **Photosythesis in the Algae.** By R. W. Krauss; Discussion by C. M. Palmer, W. J. Oswald, and H. B. Gotaas. *Ind. Eng. Chem.*, **48**, 1449 (1956).

Research into the growth of algae for water purification and food use has recently increased. The algae may provide the most efficient sustained photosynthetic system known. The biochemistry of photosynthesis is discussed in some detail.

The discussions indicate that the algae can be useful in waste treatment but that there are serious limitations. The long detention period required and the marked dependence of the process on temperature and sunlight intensity have limited the development of equipment for commercial use of algae. R. S. Ingols.

Oxidation of Soluble Oil Emulsions and Emulsifiers by *Pseudomonas oleovorens* and *Pseudomonas formieans*. By L. R. Sabina and Hilliard Pivnick *Applied Microbiology*, **4**, 4, 171 (1956).

The oxidation of soluble oil emulsions and of emulsifiers by two species of *Pseudomonas* were studied by Warburg respirometers. The two species used varied in their ability to oxidize the various oils and the same species had different powers of oxidizing the different oils.

Some oils demonstrated an increased rate of oxidation with time, indicating a possible adaptation of bacteria to the substrates. Other oils gave a decreased oxidation rate after a short period of time, indicating an exhaustion of a minor component or of the contaminating organic material. Soluble oils containing oleates were readily oxidized. There was also a marked difference in the oxidizability of various emulsifiers.

H. Heukelekian

Sewage Treatment Works, East Chicago, Indiana, 8th Annual Report, 1955. By John A. Suty.

East Chicago operates a Guggenheim biochemical treatment plant serving a contributory population of 64,800. Subsidiary sewage and storm water pumping stations are also operated.

Filtered sludge cake is disposed of for use on lawns. Acid pickling liquor and oil wastes have been troublesome.

Operating Data for 1955

Item	Average
Sewage flow (m.g.d.)	12.7
Gal./cap./day	196
Suspended solids removal (%)	95.6
B.O.D. removal (%)	96.4
Grit (cu. ft.)	3,282
Screenings (cu. ft.)	2,453
Scum (cu. ft.)	576
Effluent (p.p.m.):	
B.O.D.	5
Suspended solids	5

The aeration period was 3.1 hr. using 0.56 cu. ft. of air per gallon of sewage. The final settling detention period was 2.7 hr. Aluminum sulfate is fed to the return sludge (about 20 per cent volume of sewage) at a rate of 0.4 gr. per gallon. The excess sludge is treated with ferric chloride and lime prior to vacuum filtration.

LANGDON PEARSE

The Biology of Rivers in Relation to Pollution. By F. T. K. PENTELOW. *Inst. Pub. Health Eng.*, **55**, 2, 85 (1956).

This paper relates to the biology of rivers from a British viewpoint. Oxygen requirements at ordinary temperatures may be 2 p.p.m. for trout and salmon, and less than 0.1 p.p.m. for tench. Carp will survive in a much lower oxygen concentration than many other fish. The pH of the water is also a factor which is affected by the carbon dioxide content. Direct poisoning has been found in a few cases where inorganic wastes containing acids and metals are present.

The effect of pollution on plant life and the occurrence of photosynthesis is discussed. The effect of heating a stream by discharge of condenser water from generating stations is under observation. In the study of the biology of polluted waters, the first objective was to find "indicator organisms"; the second objective was to determine the indirect effects on fish.

A list of 10 references is appended. In the discussion 10 speakers made various comments from personal experiences. The author concluded by mentioning the stimulation of excessive growths by nitrified effluents and the need for weed removal.

LANGDON PEARSE

Metropolitan Water, Sewerage and Drainage Board, New South Wales, Australia, Year Ended June 30, 1955.

This is the annual report of the board that provides Sydney, Australia, and its environs with water, sewerage, and drainage facilities.

The water delivered during this period averaged 161.8 m.g.d. (Imp.) or 81.1 gal (Imp.) per capital. Large storage reservoirs are the source of supply.

Sydney and suburbs are served by three major and three minor sewerage systems which discharge to the ocean, and two systems which discharge to sewage treatment works. The total length of sewers was 3,252 miles and the population served totaled 1,383,833. Systematic surveys are made to remove roof and surface water.

The storm water drainage network consists of 86 systems containing 175 miles of closed and open channels.

LANGDON PEARSE

Annual Report of Commissioner of Public Works, Fitchburg, Mass. Pamphlet 609, 58 pp. (1954).

This report contains a concise summary on the operation of the sewage treatment works in 1954, at a cost of $25,300. The sewage flow from 42,000 population averaged 3.99 m.g.d. or 95 gal. per capita per day.

The Imhoff tank skimmings averaged 2.7 cu. ft. per day. The detention period in the settling chambers averaged 5.5 hr. The flow was reversed monthly. The trickling filters (1.86 acres) were loaded at the rate of 2.16 m.g.a.d. and an average of 9.4 nozzles were cleaned per day. The plant was designed to serve a population of 55,000.

The sludge drying beds (31,350 sq. ft.) were cleaned three times during the year. Approximately 75 per cent of the sludge pumped from the Imhoff tanks was dried on drying beds and the rest was lagooned. The secondary settling tanks handled the entire flow from the trickling filters, and the secondary sludge was pumped to two drying beds.

No analytical results were given. The plant was in full operation during the year reported and treated the domestic sewage satisfactorily, delivering a highly purified effluent to the North Branch of the Nashua River.

LANGDON PEARSE

Some Hydraulic Aspects of Sewerage and Sewage Disposal. By C. B. TOWNSEND AND G. W. WILKINSON. *Proc. Inst. Civil Eng.* (England), **4**, 3, 662 (1955).

This paper indicates that the proper sequence of operations in sewers and at treatment works depends on the sound application of hydraulic principles to ensure both the efficient transport of solids and their removal. Differential removal at the various stages may be required.

The need for further research is emphasized. Various problems in sewerage practice from the British viewpoint are considered, such as velocity formulae for flow in pipes, effect of sewage characteristics on design, conditions of flow, sewer junctions and drop-pipes, and side-weir overflows.

In sewage disposal, the control of velocities and levels is discussed, including the separation of suspended solids, grit chambers, sedimentation tanks (with comment on the limitations of Hazen's theory), effect of inlet and outlet conditions, and distribution of flow among units.

A general discussion and summary by 21 engineers is included. LANGDON PEARSE

The Development of Sewage Treatment in the City of Coventry. BY G. BERRY AND C. R. DALEY. *Proc. Inst. Civil Eng.* (England), **5**, 1, 41 (1956).

This paper traces the development of sewage treatment in the City of Coventry since the inception of the sewerage system in 1852. The city has grown from 65,000 in 1900 to 270,000 in 1955. There has been considerable expansion of industry in the last 50 years.

The city is traversed by three valleys, in which are located the main intercepting sewers. The treatment site at Finham has a 2 m.g.d. (Imp.) trickling filter bed (fixed nozzles) and a 1 m.g.d. (Imp.) activated sludge plant.

Experiments showed that the capacity of the Finham works could be readily increased by interpolating an activated sludge unit between the existing settling tanks and the filter beds.

Another works at Baginton includes an activated sludge plant (1 m.g.d., Imp.) and 12 filter beds (2 m.g.d., Imp.). A more or less fixed volume of sewage is being pumped to the Baginton works, leaving the Finham works to accommodate daily fluctuations of flow.

Recirculation procedure at Finham has improved the condition of the filter beds.

In 1945, a small pilot plant was constructed for experiments with recirculation and alternating double-filtration processes. These tests showed that Coventry sewage could be satisfactorily treated by the alternating double-filtration process, with an increase in the rate of dosing to the existing filters from 70 gal. per cubic yard per day to 140 gal. (Imp.). One-half hour of intermediate settling was satisfactory.

LANGDON PEARSE

The Implementation of the Public Health Acts. BY M. HOFFMAN. *Jour. Inst. Pub. Health Eng.*, **54**, 4, 271 (1955).

This is a review of the law in Great Britain pertaining to the powers and duties of the local authority, the disposal of effluent, and house connections. The rights and limitations of private persons are outlined. Discharge of petroleum spirit and calcium carbide into sewers is expressly prohibited. Trade effluents are regulated by the Public Health Act of 1937.

Schemes must be presented to the minister of housing and local government for approval. A manual of procedure has been prepared. Grants may be made for rural projects. Various committees afford technical research and guidance.

Discussion by eleven engineers follows.

LANGDON PEARSE

Construction of 60-in. Diameter Outfall Sewer for Morecambe and Heysham Corporation. BY J. K. BROOKS AND J. S. D. BROWN. *Proc. Inst. Civil Eng.* (England), **5**, 2, 302 (1956).

The paper describes the construction of the seaward length of a 5-ft. diameter steel pipe outfall sewer. The pipe passes under the seawall and extends, under fully tidal conditions, 4,160 ft. out to sea. The tidal range at ordinary spring tides is 28 ft.

The various methods considered and the method finally adopted are discussed. It was proposed that the short length inside the seawall should be carried in a tunnel which was constructed between a shaft on shore and a cofferdam on the foreshore. Owing to difficulties, this 64-ft. length of pipe was placed in a steel sheet-piled trench about 30 ft. deep. Interesting problems in maintaining the safety of the seawall during the breaking through and rebuilding are presented.

The foreshore consisted of sand and clay overlying gravel. The method adopted for the first 2,000 ft. (beach section) and the landward half of the tidal work was to work from beach level and lay the pipe in a sheet-piled trench. The access was made by a ramped timber gantry.

The seaward half of the tidal work was constructed by driving a 2,000-ft. long working gantry carrying two gauges of tracks. From the gantry, half-tide cofferdams were driven in which the pipe was laid.

Sewer construction within the steel-piled cofferdams was carried out with the aid of six 5-ton steam cranes carried on a 4-ft. 8.5-in. gauge railway track. Materials were fed to the work on a parallel 2-ft. gauge track. Piling equipment, various locomotives, wagons, pumps, mixers, etc., had to be moved to and from the beach according to the tide. This required careful marshalling and arranging of the units, since two and sometime three places were being worked at one time, and the units used varied, depending on the operation in hand.

I. VAHIDI

Bioassay for the Estimation of Metal Ions. By W. R. SHAW AND B. R. LOWRANCE. *Anal. Chem.*, **28**, 1164 (1956).

This article bases the determination of the concentration of a silver ion concentration upon the relative biological response of fishes to known and unknown concentrations of silver ions. It is shown that the concentration of silver ion from saturated silver chloride, by this method, agrees with the average value by other techniques.

R. S. INGOLS

BOOKS, REPORTS, PAMPHLETS

Newtown Creek Drainage Basin. New York State Water Poll. Control Board, Albany, N. Y. 43 pp. (1955).

Chemung River Drainage Basin Series, Report No. 1. Recommended classification and assignments of standards of water quality and purity for this basin.

Skaneateles Creek Drainage Basin. New York State Water Poll. Control Board, Albany, N. Y. 51 pp. (1955).

Oswego River Drainage Basin Survey Series, Report No. 2. Recommended classifications and assignments of standards of water quality and purity for this basin.

The Prevention of Occupational Skin Diseases. By LOUIS SCHWARTZ. Assn. American Soap and Glycerine Producers, Inc. (1955).

Presents a practical approach to occupational skin diseases, their cause and prevention.

Proceedings of the Fourth Annual Water Symposium. Bull. No. 51, Eng. Exper. Station, Louisiana State Univ., Baton Rouge, La. 118 pp. Price, $1.50 (1955).

Papers on water resources development and pollution control presented at the symposium held at Louisiana State University, March 22–23, 1955.

Oxidation Ponds—Waste Treatment Studies, Radioisotope Uptake, and Algae Concentration. By E. F. GLOYNA, E. R. HERMANN, AND W. R. DRYMAN, Univ. of Texas, Austin, Texas (1955).

A technical report prepared under contract with the Atomic Energy Commission.

Studies in Water Reclamation. Tech. Bull. No. 13, San. Eng. Res. Lab., Dept. of Eng., Univ. of California, Berkeley, Calif. 65 pp. Price, $1.00 (1955).

Reviews recent progress toward a solution to waste water reclamation problems and reports on specific findings of the Sanitary Engineering Research Laboratory, University of California.

An Investigation of Sewage Spreading on Five California Soils. Tech. Bull. No. 12, San. Eng. Res. Lab., Univ. of California, Berkeley, Calif. 33 pp. Price, $1.00 (1955).

Infiltration data were obtained on five permeable soils, and the bacterial and chemical quality of water and sewage spread on these soils was determined.

Report on Laboratory and Model Studies of Sea Water Intrusion. Tech. Bull. 11, San. Eng. Res. Lab., Univ. of California, Berkeley, Calif. 44 pp. Price, $1.00 (1955).

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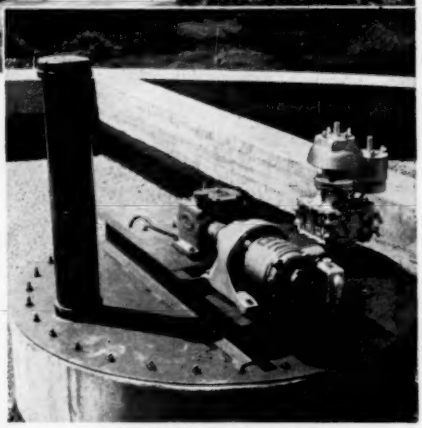

"VAREC" Fig. No. 5800C
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TEXAS WATER AND SEWAGE WORKS ASSOCIATION

The 1957 Annual Meeting of the Texas Water and Sewage Works Association was held in conjunction with the 29th Annual Short School at Texas A. and M. College, College Station, Texas, March 3–8, 1957. A total of 787 persons were registered. This does not include the 35 members of the TWSWA State Auxiliary which held its first regular business session jointly with the Short School. The general pattern of the program was similar to that followed in previous years, with special sessions being held March 4–6 for the sewage and industrial wastes groups.

At the opening meeting of the General Sewage and Industrial Wastes Session, papers of special interest were presented on Texas state public health activities, customer relations and Federal stream control.

An oxidation pond symposium was held with W. W. Towne, Chief, Water Pollution Control, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio, presiding as Chairman. Local problems were discussed by Joe Neel, USPHS, Kansas City, Kans.; Don Kalda, State Department of Health, Austin, Texas, and D. F. Smallhorst, Texas State Department of Health, Austin, Texas. A resume of research on the subject was pre-

(*Continued on page 294a*)

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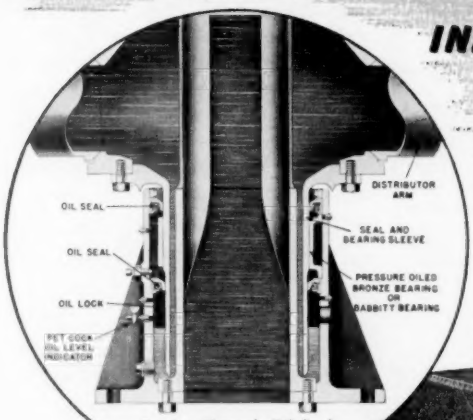

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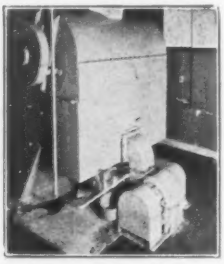

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sented by E. F. Gloyna and E. R. Hermann, both of the University of Texas.

Another highlight of the program was the Industrial Wastes Session which consisted of an all-day and evening panel discussion on the topic, "Water, Water, Everywhere But!—" A hypothetical problem was presented for critical examination by the audience and a panel of speakers provided a background of information about alternate solutions to the situation. The panel participants were: J. F. Conlon, Carbide and Carbon Chemical Co., Texas City, Texas; T. L. Satterwhite, Humble Oil and Refining Co., Baytown, Texas; David Lee, Celanese Corporation of America, Bishop, Texas; A. D. Rust, Dow Chemical Co., Freeport, Texas; J. W. Eberman, Shell Chemical Corporation, Houston, Texas; R. E. Morris, City of Dallas Water Department, Dallas, Texas; W. E. Gibson, Cosden Petroleum Corporation, Big Spring, Texas; and L. L. Hedgepeth, American Cyanamid Co., New York, N. Y.

At the business luncheon of the Texas Water and Sewage Works Association the honored guest and speaker was Emil C. Jensen, Federation President, who gave a brief resume of some of the Federation's activities.

The following officers were elected to serve the section in 1957–58:

Chairman: John F. Conlon, Texas City.
First Vice-Chairman: Roger Moehlman, Houston.
Second Vice-Chairman: T. L. Satterwhite, Houston.
FSIWA Director: A. C. Bryan, Houston.
Secretary: V. M. Ehlers, Austin.
Asst. Secretary-Treasurer: Mrs. E. H. Goodwin, Austin.

MRS. E. H. GOODWIN,
Asst. Secretary-Treasurer

(*Continued on page 296a*)

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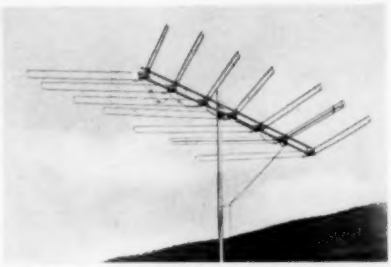

Channel Master TW Fringe area antenna.

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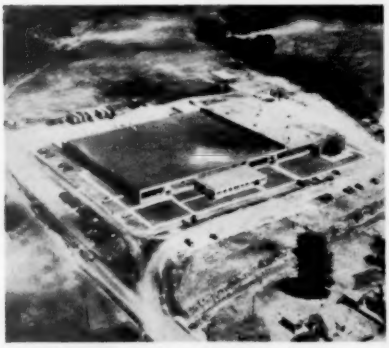

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ARIZONA SEWAGE AND WATER WORKS ASSOCIATION

The 1957 Annual Meeting of the Arizona Sewage and Water Works Association was held at the Maricopa Inn in Mesa, Ariz., April 4–6, 1957. A total of 234 persons were registered.

This meeting was considered to be one of the most successful Association Meetings so far to be held. During 1956, the Arizona Sewage and Water Works Association, in conjunction with the University of Arizona and the Arizona State Department of Health, inaugurated a water and sewage operator correspondence course program. Courses were made available at no charge to Arizona operators and it was felt that the excellent attendance at the annual meeting reflected the success of the program.

Highlights of the technical sessions were discussions on the use of sewage effluent in agriculture, chlorinator control apparatus, comparison of sewage treatment methods, and accounting and collecting procedures. A panel on sewer maintenance covered such subjects as the effect of garbage grinders on sewers, the problem of industrial wastes, and the photographic inspection of underground structures. Participants in these discussions were E. J. Umbenhauer, El Paso Water Department, Arthur Pickett of Los Angeles County, Calif., and A. A. Appel of the City of Los Angeles, Calif.

Officers were elected for 1956–57 as follows:

Chairman: Quentin Mees, Tucson, Ariz.

First Vice-President: A. L. Frick, Jr., La Mesa, Calif.

Second Vice-President: H. C. Biggle-stone, Phoenix, Ariz.

Secretary-Treasurer: Stanford I. Roth, Phoenix, Ariz.

STANFORD I. ROTH,
Secretary-Treasurer

MISSOURI WATER AND SEWERAGE CONFERENCE

The 1956 Annual Meeting of the Missouri Water and Sewerage Conference was held at Jefferson City, Mo., on September 30 and October 1–2, 1956, in conjunction with the Missouri Section, AWWA.

Papers of interest to sewage and industrial waste treatment personnel were as follows:

"Recent Developments in Water Pollution Control," by Glen Hopkins, Regional Engineer, USPHS, Kansas City, Mo.

"Putting Laboratory Results to Work," by Paul Bolton, Public Health Engineer, USPHS, Kansas City, Mo.

"Salaries of Sewage Plant Operators," by Werner Heidtke, Superintendent, St. John's Overland Sewer District, St. Louis County, Mo.

"Lagoon Studies," by Jack K. Smith, Chief, Water Pollution Control Section, Bureau of Public Health Engineering, Missouri Division of Health, Jefferson City, Mo.

The program featured panel discussions on sludge disposal and on the effects of Missouri River pollution on community water supply.

Officers elected to serve during 1956–57 are:

Chairman: Frank McAndrew, St. Joseph.

Vice-Chairman: C. Robert Hayob, Marshall.

FSIWA Director: Jack K. Smith, Jefferson City.

Secretary-Treasurer: Warren A. Kramer, Jefferson City.

W. A. KRAMER,
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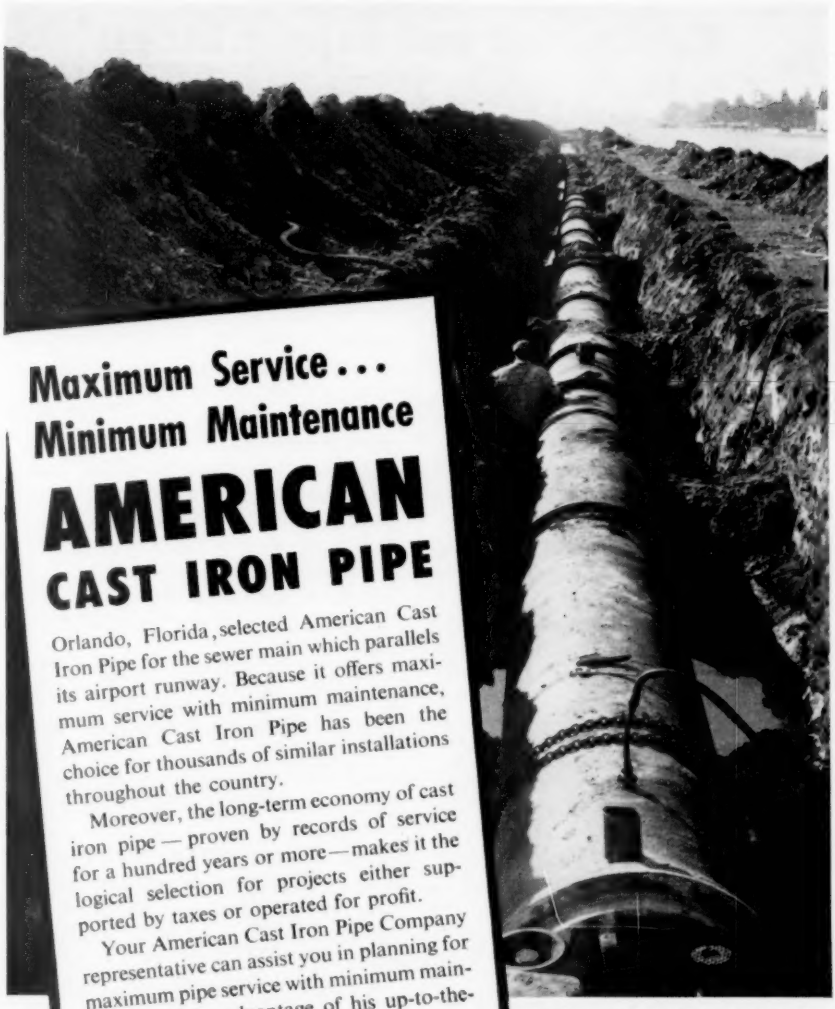

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Equipment and Supply Lines

Slurry Pump—A heavy-duty suction pump for handling abrasive slurries is introduced in Bulletin 186. —Morris Machine Works, Baldwinsville, N. Y.

Filter Underdrain Tile—Bulletin 6220 explains the design and performance of "Accelo-Hi-Cap" filter underdrain tile for high-rate trickling filters. Each vitrified, salt-glazed, fire clay block contains two large ducts to handle maximum requirements of drainage and ventilation.—Infilco Inc., Tucson, Ariz.

Slurry Feeder—High concentration slurry solutions can be handled without the detrimental factors caused by slurries clogging or corroding the pump seats or other moving parts. The "Flush-Feeder" uses a check valve assembly so that the seat of the check valve is flushed clean with water or other compatible flushing solution at every stroke of the pump.—B-I-F Industries, 345 Harris Ave., Providence, R. I.

Packaged Settling Unit—A compact packaged unit, designated the "Verti-Flo," provides for the removal of industrial wastes solids by settling. The settled solids are removed by a chain scraper and up an incline for deposit into containers. The unit is described in Bulletin 315-92.—Chain Belt Co., Milwaukee, Wis.

Mixers and Coagulators—Bulletin W-700 presents data and information on the selection of "Vorti" mixers and "Vorti-Floc" coagulators.—Infilco Inc., Tucson, Ariz.

Steel Floor Armor—An illustrated booklet describes uses of steel floor armor. Also available is a 12-page specification and installation manual, described as a specialized report and containing data and illustrative material on the latest methods for prolonging the life of industrial floors. The material is applicable to floors which receive hard usage.—Klemp Metal Grating Corp., 6615 South Melvina Ave., Chicago 38, Ill.

Activated Sludge Plants—The 12-page illustrated Bulletin No. 6510-C describes the essential features of the "Aero-Accelator" activated sludge plant for sewage and industrial wastes treatment.—Infilco Inc., Tucson, Ariz.

Coordinated Equipment—An increase in the number of equipment manufacturers offering either a complete line of sewage and industrial waste treatment equipment or "coordinated" equipment is evident from reading the latest literature. Coordinated equipment offers an opportunity to centralize equipment responsibility and to assure the installation of units that are compatible. However, it takes the mix out of "mix and match."—*Editor.*

Ditcher—A new ditcher, model 308-TP, is reported to be capable of digging to within 2¼ in. of the outside edge of either crawler. The digging wheel can be changed easily in the field.—Gar Wood Industries, Inc., Wayne, Mich.

Dry Grinding Mills—Bulletin 17-C is a 44-page catalog which describes mills for dry grinding and pulverizing. —Hardinge Co., 240 Arch St., York, Pa.

Butterfly Valve Manual—Bulletin B-2 is an exceptionally fine presentation of engineering data and operating characteristics for butterfly valves.—Henry Pratt Co., 2222 South Halsted St., Chicago 8, Ill.

Instrumentation Index—The wealth of bulletins, catalogs, and specification sheets makes the announcement of a literature index by one equipment manufacturer welcome news. Ask for Bulletin G-2 on instrumentation.—Minneapolis-Honeywell Regulator Co. (Industrial Division), Philadelphia 44, Pa.

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(Continued through page 306a)

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INDEX TO ADVERTISERS

	Page
American Brass Company	269a
American Cast Iron Pipe Company	297a
American Concrete Pressure Pipe Association	279a
American Well Works	293a
Bailey Meter Company	276a
Builders-Providence Division of B-I-F Industries	Inside Front Cover
Cast Iron Pipe Research Association	274a, 275a
Chain Belt Company	278a
Chapman Valve Manufacturing Company	281a
Chicago Pump Company	267a
Clow, James B., and Sons (Iowa Valve Division)	277a
Dorr-Oliver Incorporated	290a
Flexible Incorporated	308a
General Chemical Division (Allied Chemical & Dye Corporation)	286a
Graver Water Conditioning Company	295a
Gruendler Crusher and Pulverizer Company	294a
Homestead Valve Manufacturing Company	284a
Infilco Incorporated	273a
Lock Joint Pipe Company	Inside Back Cover
Morse Boulger Destructor Company	280a
National Clay Pipe Manufacturers, Incorporated	282a
Pacific Flush Tank Company	288a
Simplex Valve and Meter Company	271a
Smith and Loveless, Incorporated	283a
Snow Gates and Valves	292a
Vapor Recovery Systems Company	291a
Wallace and Tiernan Incorporated	Back Cover
W-K-M Division of ACF Industries, Incorporated	287a
Yeomans Brothers Company	285a

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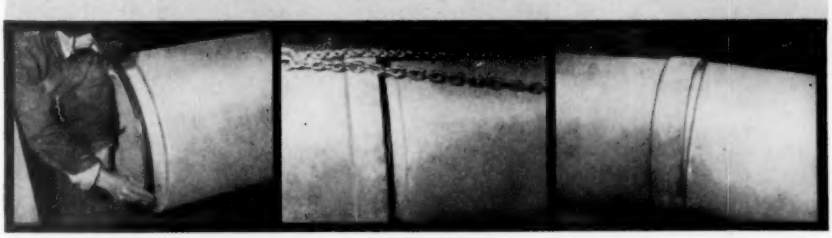

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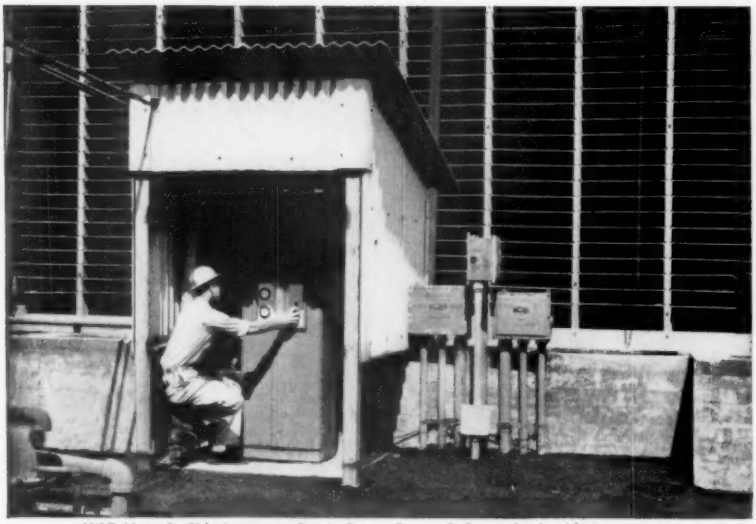

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